THE
GEOLOGICAL MAGAZINE
VOLUME LXVIII.
No. VIII.—AUGUST, 1931.

ORIGINAL ARTICLES.

The Ouachita Basin of Oklahoma *vis-a-vis* the Craven Lowlands of Yorkshire.

By E. E. L. Dixon, H.M. Geological Survey.

Contrasts in Oklahoma and in Yorkshire.

In the Geological Magazine for February the limestone-boulders in the Bowland Shales of School Share near Settle were redescribed by Dr. R. G. S. Hudson and the writer, and the conclusion reached that they represented a landslip from a fault-scarp raised along part of the Craven Fault-system during the mid-Carboniferous earth-movement. Whilst that article was in the press the writer became aware that great limestone-boulders occur in the Caney Shale of Oklahoma and that they have occasioned much discussion or even, owing to their size and varied fossils, uncertainty as to the age of the associated beds. His interest was piqued, for he recalled that a close comparison had been drawn by Bisat [1] between the contrast of Bowland Shale (Culm) and Yoredale facies of sedimentation, displayed in the Craven Lowlands and in the Craven Uplands and the Yorkshire Dales, and a contrast in Oklahoma between the sedimentation in the Ouachita Mountains and that in the nearby Arbuckle Mountains.

As a first result of going into the literature he realized the prescience of Bisat's comparison of faunas, for two species from School Share which he had ascribed, incorrectly, to that author were Caney Shale forms, viz. *Goniatites newsomi* Smith and *Sagittoceras* cf. *meslerianum* (Girty), and both came originally from the Caney Shale or its Arkansas correlative close by.

Further delving suggests that a remarkable parallelism exists between the English and American areas. The American sequence also merits our attention for its bearing on the problem of black shales, but this must be dealt with in another paper.

It is difficult, to one unfamiliar with the literature, to apportion

[1] "A Yorkshire Carboniferous (Bowland Shale) Fauna in Oklahoma, U.S.A.": *Naturalist*, 1924, 86–8.

credit for the stages of progress or to learn many of the particulars that one would like to know, but fortunately the chief points have been set forth in recent authoritative works[1]; a palaeontological account[2] by Girty was the occasion of Bisat's paper aforesaid.

A difference in sedimentation between the Arbuckle and Ouachita regions which, as displayed in the Carboniferous sequences, drew Bisat's attention, had persisted since Cambrian time. In the Arbuckles, from the close of the Cambrian to the commencement of the Avonian (Mississippian), limestones, dolomites, or, less frequently, terrigenous beds with a varied calcareous fauna were deposited, whereas in the Ouachitas shales, sandstones or cherts, nearly all non-calcareous or with restricted calcareous faunas, were being formed. The facts that sedimentation in both regions was intermittent and, as we learn from Ulrich, whose knowledge of American Palaeozoics and their fossils is unsurpassed, alternated largely from one region to the other, do not affect the significance of the difference. Neither, it would appear, does the fact that the two rock-sequences, now only 15 miles apart, were originally more distant, but have been brought close together by folding and overthrusting.

The Mississippian and lower Pennsylvanian formations which concern us are as follows, the grouping and the thicknesses in the Ouachitas being those given by Miser and Honess.

	Arbuckle Geanticline.		Ouachita Geosyncline.	
	Atoka and higher formations.			
Pennsn. (Up. Carb.)	Wapanucka Lst. (partly thick oolite).	Ft. 100	Wapanucka Lst. (confined to outcrops nearest the Arbuckles; little oolite).	Ft. 0–800
Miss.-Penn.	Caney Sh. . .	1,600	Caney Sh. . .	0–1,500
Missn. (Lr. Carb.)	Sycamore Lst. .	10–200	Jackfork Sst. .	0–6,600
	Woodford Chert .	650	Stanley Sh. . .	0–10,000
			Hot Springs Sst. .	0–200

[1] H. D. Miser and C. W. Honess, "Age Relations of the Carboniferous Rocks of the Ouachita Mts., etc.": *Oklahoma Geol. Surv.*, Bull. 44, 1927. E. O. Ulrich, "Fossiliferous Boulders in the Ouachita 'Caney' Shale and the Age of the Shale containing them," Bull. 45, 1927. S. Powers, "Age of the Folding of the Oklahoma Mts., etc.": *Bull. Geol. Soc. Am.*, xxxix, 1928, 1031–72; also maps on the 1 : 500,000 scale, published by the Federal and Arkansas Geol. Surveys, of Oklahoma (1926) and Arkansas (1929).

[2] "The Fauna of the Caney Shale of Oklahoma": *U.S. Geol. Survey*, Bull. 377, 1909.

In the Arbuckles the rocks on the whole have been gently folded and broadly uplifted. The Ouachita rocks, on the other hand, have been sharply folded and overthrust from the south. They are completely separated from the Arbuckles by a great boundary-overthrust, the Choctaw Fault, which reaches the surface along the north and west (Fig. 1). Ulrich claims that they have been transported in Alpine fashion from some site, now beneath younger rocks, a hundred miles or more to the south. Be this as it may they may well have been thrust, along this plane or an adjacent one, over the

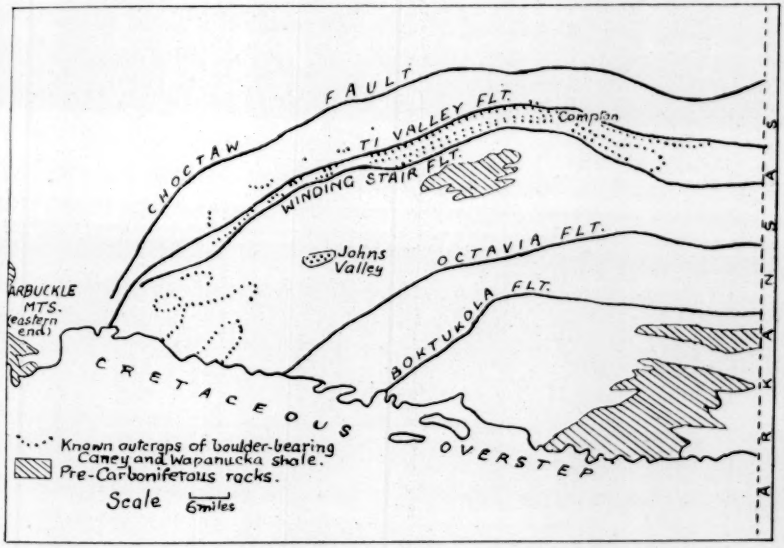

FIG. 1.—Outline Map of the Ouachita Mountains in Oklahoma. From S. Powers, op. cit., fig. 3.

southern part of the area of sedimentation of the Arbuckle rock-types, an important suggestion put forward by Powers which, as we shall see, appears to help materially towards solving some of the problems of the region.

The contrast between the movements, both of them Hercynian, in the Arbuckles and Ouachitas respectively recalls the difference between the even lie of the Carboniferous in the Craven Uplands and the Dale country generally and the repeated folding, sharp in places, and faulting in the Craven Lowlands. The Choctaw Fault would correspond to the main Craven Fault. In Oklahoma, however, movement has been vastly more intense than in Yorkshire.

The Oklahoma Boulders and the Period of their Accumulation.

Only what appear to be the salient facts need discussion here. The boulders are confined to the outcrops of Caney Shale (and Wapanucka Limestone) that lie in the Ouachita region, and they are predominantly limestones. In these fundamental respects they parallel the boulders of School Share and Cracoe, which are in the Craven Lowlands, the counterpart of the Ouachitas. In other respects, however, they display striking differences. Whereas the Yorkshire boulders are entirely of Carboniferous Limestone, those of Oklahoma have been derived from a variety of formations, Cambrian to Mississippian, and, according to Ulrich, early Pennsylvanian. Further, though in both regions the boulders are "exotic", the exposed outcrops of the parent formations are less than a mile distant in the case of Craven, but 15 miles or more away in the Arbuckles.

Again, although the Craven boulders are certainly large, those in the Ouachitas run to lengths of 50 feet or more, and a few are positively gargantuan, measuring up to 550 feet by 65 feet These last, found by Powers in Johns Valley, are exceptional and will be discussed later.

A comparison in respect to the period of boulder-accumulation, though vital to our purpose, is difficult owing to the different bases of classification of the Carboniferous in the two countries. Much of the discussion, apparently by no means finished, about the Oklahoma sequences concerns the horizon at which to separate Pennsylvanian from Mississippian. Elsewhere in America these divisions are usually more or less obviously unconformable. In Oklahoma they are apparently conformable and the groups near the junction are either almost unfossiliferous or have a goniatite-lamellibranch (culm phase) fauna. Fortunately we need consider only the group with Culm affinities, the Caney Shale. Its taxonomic position has been in doubt because its fauna is unlike that of any of the well-known Carboniferous formations in America. But, largely on account of certain formations intermediate in geographical position and in character, the lower part is now correlated by Girty [1] with the Mississippian, the upper part being Pennsylvanian. This correlation appears to be generally accepted. The lower part, however, is that which contains the goniatites on the strength of which Bisat has concluded that the Caney Shale is partly Viséan, partly Namurian. In other words, it would appear that the boundary in the Caney Shale between Viséan and Namurian is rather lower than that between Mississippian and Pennsylvanian,[2] a view that

[1] Op. cit.; and in Miser and Honess, 23–4.

[2] Delépine comes to the same conclusion and for the same reason ("Les Zones à Goniatites du Carbonifère," *Soc. Géol. de France Livre Jubilaire*, 1930, 228).

presupposes that the goniatites have the same sequence in the Caney Shale as in Europe. Ulrich has remarked that comparison of the Lower Palaeozoic shales of the Ouachitas with the totally dissimilar strata of the adjacent Arbuckles has been made by way of Appalachian and British graptolite-zones. Probably an exact comparison of Namurian with lower Pennsylvanian will be made by means of the goniatite-zones of Bisat.

As well, however, as uncertainty as to the goniatite-sequence in the Caney Shale, doubt enters from another quarter. Ulrich believes that the Caney Shale of the Ouachitas, which alone interests us at present, has no indigenous macrofossils and that all its Mississippian "Caney" fossils (chiefly goniatites and lamellibranchs) are derived, like the limestone-boulders that it contains. Consequently he regards it as entirely Pennsylvanian and distinguishes it from the true Caney Shale of the Arbuckles as "Johns Valley Shale". This view does not appear to be generally accepted.

In one respect at least the distribution in time of the boulders is different in Oklahoma from that in Yorkshire; they occur on more than one horizon whereas here they are confined to the base of the Namurian (Upper Bowland Shales, E_1). In Johns Valley, Powers finds, there are two boulder-beds, that with the huge blocks previously mentioned being near the black base of the shale. He goes on, "north of Compton Cut there are three or four boulder-bearing beds. . . . At other places there are no boulders in the lowest Caney black shales, and the overlying boulder-bearing shales are gray, not black. Boulders occur also in the Wapanucka." [1]

In the Ouachitas, therefore, the boulders have a somewhat greater time-range than here. If Ulrich is right in regarding the "Caney" fossils in Johns Valley as derived and if the boulders there are associated with derived *Eumorphoceras bisulcatum* (see Girty's list, op. cit.), the time-range in America is also somewhat later than here. If, on the other hand, the fossils are indigenous, the lowest boulders presumably, from the occurrence of *G. newsomi* and *S.* (*Adelphoceras*) *meslerianum*, accumulated in Lower Bowland Shale (P_2) time, i.e. before those of School Share, and the higher boulder-horizon at Johns Valley might represent the level of the latter.

In either case we have, as here, an association of boulders with mid-Carboniferous black shales (Schuchert's "Bendian"). The difference in range of time of accumulation between the boulders in the Ouachitas and those in Craven may have been due to the preceding faulting (see later) having been more prolonged, as it certainly appears to have been more intense, in the Ouachitas.

[1] It is difficult to fix the position, in this country, of the Wapanucka Limestone, as it is not developed with the same facies. It is generally regarded as the base of the Pennsylvanian and its horizon, therefore, it not far from the base of the Namurian.

It should be noted that our Lower Bowland Shales, though unaccompanied by boulder-formation, are believed by Hudson[1] to have followed a period of faulting.

Mode of Transport and Relation to Earth-Movements.

It is when we come to the suggested mode of transport that we encounter an apparently vital difference. In Craven boulders crop out immediately south-west of a scarp of Carboniferous Limestone, probably a fault-scarp of mid-Carboniferous date, still partly buried in Upper Carboniferous muds and sands. None of the boulders are striated, and there is no need to seek a mode of transport other than mid-Carboniferous landslipping. But no old scarp rises above the Ouachita boulders, and as in some places these are deeply striated and at various localities blocks too large for ordinary means of transport have been found, the explanation has been advanced that they have been conveyed by land- or shore-ice or by bergs.

This explanation, which has received general assent, is, however, not free from difficulties. The striae are not accepted by some glacialists, and those at Compton Cut, though several have been figured as glacial,[2] are stated definitely to be due to slickensiding.[3] Compare Wickham King on the "glacial" striae in the Clent Breccia. It may be mentioned also, *en passant*, that probably ice could not have existed in the Wapanucka Limestone sea, where oolite was being formed. The somewhat similar objections to glacial transport raised by Ruedemann in the case of the Trenton conglomerate of Rysedorph Hill and by Bailey, Collet, and Field[4] in that of the Beekmantown boulders associated with the Lévis Shales seem to be unanswerable.

The huge boulders in Johns Valley present special difficulties to any theory. Powers is uncertain whether the theory of ice-transport is adequate in their case. They seem rather to invite comparison with the great block,[5] 150 feet long, in the Kimmeridgian Boulder Beds of Brora; regarding these boulder-beds opinion has definitely changed from glacial deposits to a series of cliff-falls. It is difficult, however, to extend this theory to the Johns Valley boulders, because not only is there no evidence of an adjacent scarp of Lower Palaeozoic limestones but the Caney Shale is there surrounded for some distance by the underlying Mississippian group, the Jackfork Sandstone. Equally large blocks

[1] *Proc. Geol. Assoc.*, xli, 1930, 316–17.
[2] E. O. Ulrich, op. cit., pls. iii, v, and vi.
[3] S. Powers, op. cit., 1046.
[4] "Palæozoic Submarine Landslips near Quebec City": *Journ. Geol.*, xxxvi, 1928, 606–7.
[5] M. Macgregor, "A Jurassic Shore-line": *Trans. Geol. Soc. Glasgow*, xvi, 1916, 79, 84, and pl. iii.

are, of course, found in truly glacial boulder-clays, but serious objections can be raised to land-ice transport of the Caney boulders. Floating ice is less open to criticism, but is also less capable of delivering the goods.

As an alternative to ice-transport Powers (and R. C. Moore) suggest (p. 1046) that a slice of the old Arbuckle limestones—many of the huge masses are apparently the Ordovician Viola Limestone—was thrust from the north over the Jackfork Sandstone in late Mississippian time and that the Johns Valley boulders are fragments from the uplifted block buried in the ensuing Caney Shale. The root of the uplift is supposed to have been, not among the known limestone-outcrops in the Arbuckles, but in an extension of similar limestones beneath the northern part of the Ouachitas. "All traces of this uplift would now be covered by overthrusts [i.e. the Hercynian set] from the south." The part played by glacial action, in his summing-up, is reduced to that of a possible accessory after the fact.

Recent authoritative opinion, then, on the most puzzling of the Oklahoma boulders suggests a mode of origin that differs little in essentials from what appears to have happened on a much smaller scale (but has been left unobscured by later disturbance) along the Craven fault-zone. That is, a local, late Mississippian uplift of limestones of Arbuckle types in the northern part of the Ouachitas was followed by burial of fragments of the limestones in the ensuing Caney Shale, possibly after some distribution by shore-ice. Consequently it appears possible—at this distance from the evidence !—to explain the rest of the Oklahoma boulders on similar lines, especially as the necessity of bringing them from the Arbuckles (whence largely the hypothesis of ice-transport) disappears in face of the suggestion that similar rocks underlie the northern edge of the Ouachitas.

That the boulders in Oklahoma and in Craven have had a cognate origin is supported by two pieces of evidence. In the first place most at least of the rest of the Oklahoma boulders have been found near the intensely faulted northern border of the Ouachitas, and none further away than those of Johns Valley ; along the border they extend for a distance of 100 miles. It would appear, then, that they could have come directly from a great fault-scarp of old limestones, raised in late Mississippian time near this stretch of the border but now shaved off and its root covered, like the unraised part of the limestones, beneath the overthrust edge of the Ouachita sediments.

Secondly, the Stanley Shale and Jackfork Sandstone, though widespread with a thickness of 12,000 feet in all over much of the Ouachitas, do not extend quite to the Choctaw Fault along the northern border but end abruptly at the Ti Valley Fault, a parallel overthrust a short distance to the south (Fig. 1). Between the two faults the succeeding Caney Shale rests directly on the Woodford

Chert (Devonian ?).[1] The disappearance of the formations has given rise to much discussion and various explanations, none apparently satisfactory. The rapidity of the disappearance, the fact that it occurs near an important line of tectonic weakness, and the absence from the shales and sandstones (so far as their description goes) of evidence of proximity to a shore-line suggest that they have been either overlapped by the Caney Shale at a submarine bank,[2] probably a fault-scarp along that line, or overstepped by the Shale after uplift on the north by a fault along the same line. In either case an upthrow of Mississippian age, parallel to the northern border of the Ouachitas, appears to be indicated.

Conclusion.

Hence, in explanation of the evidence as a whole it is suggested that another parallel but much greater uplift, somewhere near the position of the later (Hercynian) Choctaw Fault, brought up at the close of Jackfork Sandstone time a long and high fault-scarp of a variety of Palaeozoics, chiefly limestones of Arbuckle types, and that successive landslips from this scarp slid out over the Caney Shale collecting at its foot. The landslips may well have been caused by earthquakes in the manner suggested by Bailey, Collet and Field for the Lévis limestone-boulders, but whether the hypothesis of transport by shore-ice is necessary remains to be seen.

The great Johns Valley boulders, of Ordovician material but underlain and surrounded by thick Mississippian sediments, stand apart. To conform with the view just outlined it can only be hinted that they may have slipped from a horst standing out in front of the main fault-scarp and that all other traces of the horst have been obliterated by the intense later disturbances.

The magnitude of the supposed fault-scarp for a mid-Carboniferous creation presents difficulty. It must be remembered, however, that in America this period is regarded by Ulrich as one of the four greatest diastrophic periods. The paucity (so far as can be learnt) of boulders in the Caney Shale between the Choctaw and Ti Valley Faults is also puzzling, but similar difficulties apply to other explanations. Testing them all in the field will alone get at the truth.

[1] See, e.g., Ulrich, op. cit., Bull. 45, 27; and Miser and Honess, op. cit., fig. 2 and p. 25. These authors clearly regard the contact as one of original deposition.

[2] As shown, without committing themselves, in Miser and Honess, fig. 2A.

Garnet-bearing Sands of the Northumberland Coast.

By L. Hawkes, D.Sc., and J. A. Smythe, Ph.D., D.Sc.[1]

Contents.

1. Introductory and Field Occurrence.
2. Comparison of the Sands.
3. The Sizes of the Predominant Minerals.
4. Notes on the Minerals.
5. The Barytes of the Collywell Sands.
6. The Budle Sands.
   Fractions. Monazite.
   Zircon.
   Rutile.
   Opaque bar-magnetic minerals.
   Opaque weakly-magnetic minerals.
   Garnet.
7. The Whin Sill as a Contributor to the Coastal Sands.

1. Introductory and Field Occurrence.

IT has long been known that garnet and other heavy minerals occur in many of the sedimentary beds of the North of England. Among such, where visual proof is easy, are the Inghoe Grits, particularly at Shaftoe, and the Dunstanburgh sandstone at Cullernose Point. Hutchings[2] examined washings of the shales at Seaton Sluice and found zircons in large numbers, along with angular colourless garnet, rutile, anatase, tourmaline, sphene and barytes. In a later study by the same author[3] of the sedimentary beds metamorphosed by the Whin Sill, it was shown that small garnets are very plentiful, especially in the calcareous shales, and are accompanied by augite, hornblende, epidote, sphene, idocrase, wollastonite and other minerals. Kellett[4] made an extended investigation of the heavy minerals in the Coal Measures of County Durham and found 0·4 per cent of these in the sandstone under the Hutton seam (this is the only datum of Kellett's strictly comparable with our results). Zircon proved to be the commonest mineral in these beds; next in order came rutile and tourmaline, while garnet was quite subsidiary.

So far as we know, however, there is no published record of garnetiferous sands from the coast of Northumberland. They were observed at Budle by one of us in the year 1925, and recorded two years later.[5] Since then they have been found at several other places along the coast, details of which will be given presently, and we have lately become aware that they have been observed more than

[1] The second named author has carried out the field and practical part of this investigation, with the exception of the optical determination and counting of the mineral grains, for which his colleague is responsible.

[2] W. M. Hutchings, Geol. Mag., 1890, 264, 316.

[3] Ibid., 1898, 69, 123.

[4] J. G. Kellett, *Proc. Univ. Durham Phil. Soc.*, vii, 1927–8, pt. iv, 208.

[5] J. A. Smythe, *The Vasculum*, xiv, 1927, 17.

a century ago, for in the collection of the late Sir Walter Trevelyan, at Wallington, is a small tube labelled " sand containing garnets, iron and iserine from Bamburgh, Northumberland, 1819 ".

In all cases which have come under our observation, these sands occur at the high-water mark and, except at Collywell Bay, in positions where there is a great deal of blown sand. They occupy, with respect to the ordinary siliceous and shelly sand of the coast, somewhat the position of storm beaches. Shelter of some sort seems to be necessary for their accumulation.

At Budle they occur, to some extent, near Heatherhouse, just west of Budle Pier, but they are best developed along the short stretch of coast east of the Pier and between it and the small promontory formed by the Black Rock, mere streaks of the pink sand being formed beyond this point. This beach is extremely wind-swept and observation in high westerly winds shows that but little of the heavy minerals is carried past the point by wind action, the effect of high winds being rather to cover up the rich garnet-bearing sands with lighter siliceous sand.

Proceeding down the coast, the next locality, about a mile away, is Bamburgh. The sands here have been under occasional observation for about five years, but no garnet-concentrates have been observed. The heavy minerals in these sands only amount to 0·05 per cent and contain garnet and opaque ore with rare zircon and Whin Sill fragments. The sample of natural concentrate in the Wallington collection only weighed 3·8 grams, but this has sufficed for comparison with the other rich sands.

No other concentrates have been observed north of the Coquet. South of this is Druridge Bay, some six miles long, fringed with sand dunes except at the two extremities, where rocky outcrops occur. Near Amble, at the north end of the bay, the garnet-bearing sands are rich and of wide extent ; they tail off southwards towards the Hadston Carrs, and are lost where the rock disappears. No trace of them can be seen for four miles, but they reappear at the south end, near Cresswell, close by the rocky outcrop of The Scars. Another sandy bay stretches from the mouth of the Wansbeck, by Cambois (pron. Cammis) to Blyth. At The Rockers, near the south end of this bay, the heavy sands are again found.

The Blyth Sands stretch for two miles from the harbour of Blyth to Seaton Sluice. No rock crops out except near Seaton Sluice, and there is a large expanse of links and dunes. Garnetiferous sands are found near the south end of this stretch and in a slight embayment in the blown sand, caused by the erosion of a small stream.

In Collywell Bay, on the south side of Seaton Sluice, the coast is rocky and without blown sand. The garnet-bearing sands are found at the south end of the little bay, hard by the massive sandstone of Crag Point.

These constitute the main occurrences so far observed, though streaks of heavy mineral concentrates are to be seen on the Whitley

Sands and in other places. There can be little doubt that water action is the main factor concerned in the concentration of the heavy minerals. At each ebbing tide, small runnels drag the coloured minerals in streamers down the beach, to be thrown up by the next flowing tide. There are many bays on the coast, where the conditions for accumulation would appear to be quite as favourable as in the cases just cited, e.g. Embleton Bay and Beadnell Bay, the careful and repeated scrutiny of which has failed to disclose more than a trace of heavy minerals. It might be argued from this that the source of the heavy minerals is lacking locally, but it is obvious that observation over a long period would be necessary before the value of this negative evidence could be appraised, and the finding of concentrates at Bamburgh, more than a century ago, where now is only ordinary siliceous sand, must make one chary of drawing premature conclusions. Indeed, much depends, in this matter, on the winds and tides, the sand-concentrates being best exposed after fairly heavy seas. A long spell of quiet seas and winds offshore tends to cover up the garnet sands with blown and water-borne siliceous sand.

The richness in heavy minerals of some of the sand-concentrates is remarkable. Some samples, collected only with ordinary care, contain over 90 per cent of heavy minerals. These concentrates are often in layers, several inches thick, stratified with siliceous sand. The best of them is that of Budle and this has been examined in some detail, partly because of its intrinsic interest, partly with a view to determining the origin of the heavy minerals. The others have been systematically examined for the purpose of comparison with one another. This part of the work will be described first and will be followed by the more complete investigation of the Budle sand.

2. Comparison of the Sands.

The proportions of heavy and light minerals were determined on 10-gram samples by separation with bromoform (S.G. 2·8). Larger samples of 30–50 grams were screened through sieves having 40, 60, 80, 100, and 120 meshes to the linear inch, and the various fractions examined with respect to their content of magnetic minerals (attracted by a strong sheathed horse-shoe magnet) and, microscopically, by counting the various minerals in several hundred grains of each fraction. Similar counts were made on the virgin (unseparated) sands. The data are given in the table on p. 348.

These results bring out clearly some of the variations among these sands. The extremes with respect to grain size are Budle and Collywell, Budle being the finest and Collywell the coarsest. Collywell is richest in magnetic material. Bamburgh and Budle are the poorest, and among the heavy minerals the ratio of non-magnetic to magnetic varies from 35 : 1 to 2·4 : 1. The coarsest fractions (40—80 mesh) contain the bulk of the magnetic minerals, and the

	Budle.		Bamburgh.		Amble.		Cresswell.		Cambois.		Blyth.		Collywell.	
1. *Bromoform Separation.*														
Heavy Crop { Non-magnetic	90·9		46·2		81·0		77·5		54·6		75·0		63·0	
Heavy Crop { Magnetic	2·6		1·4		11·5		5·0		10·0		3·0		26·0	
Light Crop	6·5		52·4		7·5		17·5		35·4		22·0		11·0	
	100·0		100·0		100·0		100·0		100·0		100·0		100·0	
2. *Screenings.*														
Over 40-mesh	tr.		3·2		8·6		10·3		10·4		4·3		15·0	
40–60 ,,	12·2		46·1		35·7		44·0		34·6		28·4		54·5	
60–80 ,,	53·4		47·1		48·0		40·0		35·7		47·4		29·0	
80–100 ,,	29·6		3·6		7·3		5·4		16·0		18·6		1·5	
100–120 ,,	3·6		tr.		0·4		0·3		2·3		1·3		tr.	
Under 120-mesh	1·2		tr.		tr.		tr.		1·0		tr.		tr.	
	100·0		100·0		100·0		100·0		100·0		100·0		100·0	
	A	B	A	B	A	B	A	B	A	B	A	B	A	B
3. *Distribution of Magnetic Minerals in the Fractions.*														
Over 40-mesh	—	—	not	det.	0·4	3·8	0·2	2·0	0·6	5·8	—	—	2·7	17·8
40–60 ,,	0·2	1·5			2·8	6·5	1·7	3·4	2·0	5·8	0·4	3·5	12·8	23·6
60–80 ,,	0·7	1·7			7·1	12·2	2·6	5·8	4·0	11·2	1·5	7·0	7·2	25·3
80–100 ,,	1·2	4·9			1·2	13·6	0·5	9·4	2·6	16·2	1·0	10·8	3·3	25·0
100–120 ,,	0·3	8·3			—	—	—	—	0·3	11·5	0·1	25·0	—	—
Under 120-mesh	0·2	28·3			—	—	—	—	0·1	10·0	—	—	—	—
Total magnetic minerals in the sample (per cent)	2·6				11·5		5·0		9·6		3·0		26·0	

A = p.c. of sample. B = p.c. of fraction.

proportion of these in the separate fractions increases with the fineness of grain down to the 100-mesh.

The table on pp. 350–1 gives the results of the microscopic counts and shows the nature and distribution of the minerals, both in the virgin sands and the screening fractions. The figures are percentages in each case.

3. The Sizes of the Predominant Minerals.

The following table gives the average composition of all the seven sands arranged according to size (the S.G. of the minerals in brackets) :—

	Shell (2·8)	Quartz (2·65)	Garnet (3·8)	Augite (3·4)	Barytes (4·5)	Opaque (4·6–5·2)	Rutile (4·2)	Zircon (4·7)	Monazite (5·1)
Over 40-mesh	5·6	29	44·4	—	2·4	18	—	—	—
40–60	3·9	29	46	0·6	3·0	17	0·14	—	—
60–80	2·2	16·2	43·6	1·4	5·1	28	2·3	1·36	—
80–100	1·0	5·4	36·0	1·6	6·0	42	4·6	6·0	0·14
Under 100	0·1	1·8	15	0·6		57	4·0	19·3	1·6

The constituents of the individual sands conform to the above averages, with the following exceptions :—

Garnet.—Budle and Bamburgh show the largest contents of this mineral in the coarsest grade.

Quartz.—Budle and Cambois show smaller contents in the coarsest grade.

Rutile.—Budle and Bamburgh show highest contents in the finest grade.

On examining the average figures it is seen that the size-distribution is governed by the specific gravities of the mineral species. The lighter constituents, shell and quartz, decrease in amount with decrease in size, and the heavier minerals, opaque ore, rutile, zircon, barytes and monazite increase in amount with decrease in size. Garnet and augite, with intermediate gravities, rise to maxima and then fall. The decrease of the rutile content generally experienced in the finest grade is due to the greatly increased proportion of zircon in that grade. This is illustrated by the fact that in the Budle and Bamburgh sands, which show maximum rutile contents in the finest grade, the zircon contents of that grade are abnormally low. One may surmise that the fine quartz in the Amble and Cresswell sands has been carried in by the wind.

In the graph illustrating these relationships (Fig. 1) shell and quartz are grouped together, and also rutile and zircon. The way in which the lighter constituents predominate in the larger sizes,

		Opaque Minerals.	Garnet.	Rutile.	Zircon.	Quartz.	Carbonate.	Barytes.	Other Minerals.	Remarks.
Budle.	Virgin Sand . . .	13·8	60·5	1·8	0·3	16·3	3·0	—	4·3	Of the other minerals, 3·7% is augite.
	Fractions. Over 40-mesh	2	97	—	—	1	—	—	—	This sand is rich in garnet and augite, poor in opaque minerals, zircon, and monazite.
	40–60 . .	5	71	—	—	19	4	—	1	
	60–80 . .	7	54	0·5	—	30	4	—	4·5	Other minerals found are: Apatite, anatase, brookite, olivine (?), hypersthene, tourmaline, kyanite, sphene, and staurolite. Some bluish-green grains appear to be garnet.
	80–100. .	12	66	1·5	—	13	1	—	6·5	
	Under 100 .	24	55	4	3	1	—	—	3	
Bamburgh.	Virgin Sand . . .	6·7	33·8	0·6	0·1	47·6	8·7	—	2·5	The virgin sand contains 2·5% of augite. Apatite, tourmaline, and staurolite are also present.
	Fractions. Over 40-mesh	2	81	—	—	10	7	—	—	
	40–60 . .	5	31	—	—	54	9	—	1	
	60–80 . .	6	33	1	—	47	9	—	4	
	80–100. .	25	42	2	—	21	5	—	5	
	Under 100 .	66	19	5	8	—	1	—	1	
Amble.	Virgin Sand . . .	63	25	3	6	2	—	1	—	Largely composed of opaque minerals and garnet. The ore-minerals are sometimes attached to semi-opaque glass. Augite and monazite are rare. One grain of hypersthene and one of olivine (doubtful) were observed.
	Fractions. Over 40-mesh	21	32	—	—	43	1	3	—	
	40–60 . .	31	52	1	—	13	1	2	—	
	60–80 . .	56	32	4	5	1	—	2	—	
	80–100. .	76	6	2	13	1	—	1	1	
	Under 100 .	64	—	1	24	7	—	—	4	

CRESSWELL.	Virgin Sand . . .	33	50	2·5	3	9	1	1	0·5	Augite and monazite not uncommon. There is also some hypersthene and staurolite.
	Fractions. Over 40-mesh	12	55	—	—	25	7	—	1·0	
	40–60 . .	17	61	—	—	19	2	—	1·0	
	60–80 . .	33	60	3	0·5	3·5	—	—	—	
	80–100. .	60	23	6	9	1	—	0·5	0·5	
	Under 100 .	64	4	4	20	4	—	1	3	
CAMBOIS.	Virgin Sand . . .	50	22	3·5	6	17	—	1·5	—	Some of the garnets are yellow and one is bluish-green (doubtful). Other minerals present are augite, sphene, tourmaline, epidote, and staurolite.
	Fractions. Over 40-mesh	34	12	—	—	47	7	—	—	
	40–60 . .	25·5	10	—	—	62	2·5	—	—	
	60–80 . .	40	24	3	—	30	1·5	1·5	—	
	80–100. .	46	33	8	10	1	—	2	—	
	100–120 .	53	12	8	24	—	—	2	1	
	Under 120 .	55	4	4	32	—	—	2	3	
BLYTH.	Virgin Sand . . .	38	46	5	3	5	1	2	—	Mainly garnet and iron ore-minerals. Also present are augite, monazite, staurolite, tourmaline, and microcline.
	Fractions. Over 40-mesh	17	17	—	—	51	13	2	—	
	40–60 . .	17	40	—	—	34	7	1	1	
	60–80 . .	24	67	3	1	2	—	2	1	
	80–100. .	37	47	8	4	—	—	3	1	
	Under 100 .	62	2	3	28	—	—	3	2	
COLLYWELL.	Virgin Sand . . .	48	29	1	2	2	—	18	—	This sand is rich in barytes; zircon and rutile are rather scarce and apatite and carbonate rare. One grain of iron ore had a tachylitic border. Only one grain of monazite and staurolite were detected. The finest fraction (under 100-mesh) was mainly composed of comminuted barytes, some of it possibly produced in the sieving process.
	Fractions. Over 40-mesh	39	17	—	—	28	4	12	—	
	40–60 .	20	55	—	—	5	2	18	—	
	60–80 . .	28	35	2	3	—	1	31	—	
	Under 80 .	46	4	1·5	11	—	—	36	1·5	

and the heavier in the smaller, is evidence of the current sorting which has been responsible for the formation of these natural concentrates.

4. Notes on the Minerals.

The "carbonate" refers almost entirely to shell fragments of aragonite. Very rarely clear calcite grains were seen, and these were well rounded with no trace of cleavage; clearly the rounding of a mineral so easily cleaved as calcite must be due to wind action. Tourmaline is rare and of the brown variety. Felspar, mostly microcline, is very rare, and only one grain of muscovite was seen.

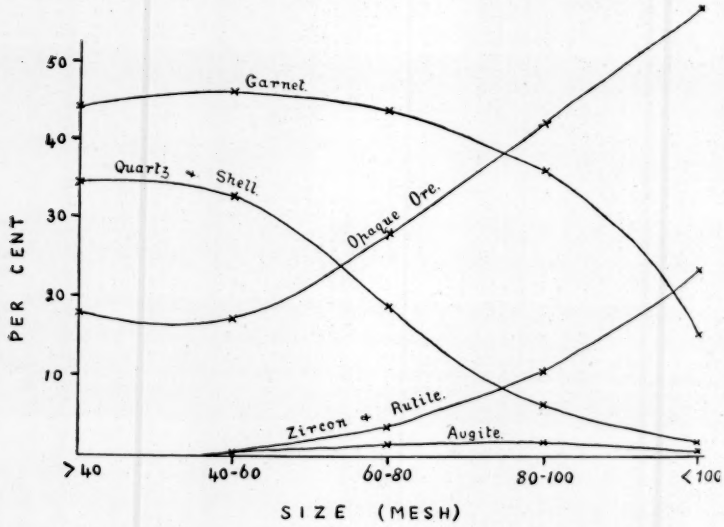

Fig. 1.—Illustrating the specific gravity control of the size-distribution of the minerals of the sands.

Sphene and apatite are also very rare. The augite is brown, often with a purplish tint. The bluish green isotropic mineral—referred to garnet—is very rare. Its R.I. > 1·77 and some grains showed minute inclusions and a feeble birefringence. It is impossible to state whether this is garnet or spinel. The bluish tinge is not recorded in garnet, but the inclusions and anomalous birefringence indicate garnet rather than spinel. The zircons include a small proportion of the "purple" variety.

All the minerals proved by Gilligan[1] in the Millstone Grit of Yorkshire are found, with the exception of cordierite and topaz, although tourmaline is common in the grits and rare in the sands. All the minerals found by Kellett[2] in the Durham Coal Measures

[1] A. Gilligan, *Quart. Journ. Geol. Soc.*, lxxv, 1919, 267.
[2] J. G. Kellett, op. cit.

are present, with the exception of sapphire (chlorite, limonite. pyrites, siderite and biotite). Minerals occurring in the sands and not recorded in the Carboniferous are augite, hypersthene, olivine (?), staurolite, kyanite and yellow and bluish green garnet (?).

There is some probability that the augite in the sands is derived from the Whin Sill, as it is especially prominent at Budle and Bamburgh. It would appear that the bulk of the heavy minerals is derived from Carboniferous sediments. The almost entire absence of muscovite is noteworthy. Stuart[1] comments on its absence from the dune sands of South Wales, and the easy transportability and facility with which the mineral is broken up will account for its non-deposition in the sands and its incorporation in the finer sediments of deeper waters.

The great variation in composition and the relative abundance of constituents in these contemporaneous sands within a small area does not lend any support to the hope that it is possible to correlate the Coal Measures by means of their heavy minerals, and it is not surprising that Kellett failed to establish any such correlation.

5. The Barytes of the Collywell Sands.

The great abundance of barytes in the sand-concentrates of Collywell Bay and its comparative scarcity elsewhere suggests that there must be some local supply of the mineral. No barytes deposits are, however, known in the immediate neighbourhood, the nearest recorded being in the Magnesian Limestone at Marden, near Cullercoats, about four miles south.[2]

In the cliff at Collywell there is preserved by faulting the most northerly exposure of the Permian Yellow Sands in Northumberland,[3] and it was thought that possibly this might be rich in barytic cement. The only account of the mineral examination of the local Yellow Sands we can find is that of Burton,[4] who examined the rock of Frenchman's Bay and the Trow Rocks near South Shields and found 0·2 per cent of heavy minerals, consisting mainly of garnet, tourmaline, rutile, zircon and opaque ore; there is no mention of barytes.

The yellow sands from Collywell were accordingly examined. The proportion of heavy minerals is of the same order as found by Burton and they consist of well-rounded garnet, with rare zircon and staurolite. The main constituent is quartz and there is a considerable proportion of microcline; there appears to be some secondary barytes attached to the grains, though the optical proof is unsatisfactory, owing to the small size and intergrowth of the

[1] A. Stuart, *Proc. Geol. Assoc.*, xxxv, 1924, 327.
[2] J. A. Smythe, *The Vasculum*, viii, 1922, 93.
[3] This fine section has been almost covered in recent months by the building of a sea-wall.
[4] R. C. Burton, Geol. Mag., 1911, 299.

crystalline cement. Chemical analysis shows definitely the presence of barytes, the composition of the material (calculating alkalis as felspars) being :—

Orthoclase . .	9·11
Albite . .	2·97
Barytes . .	0·09
Al_2O_3 . .	0·79
Fe_2O_3 . .	0·21
CaO . .	0·10
MgO . .	none
H_2O . .	0·77
Quartz by difference	85·96
	100·00

When a sample of this sand was well shaken for some time and then passed through a 120-mesh sieve, the fine material contained 0·46 per cent of barytes, i.e. five times the amount in the virgin material. It is evident, then, that these yellow sands are slightly cemented with barytes, though they are incapable of furnishing the barytes in the shore sands, the origin of which remains unknown. It may be mentioned, incidentally, that the yellow sands at Cullercoats, though strongly bound in parts with a calcareous cement, have evidently also some barytic bond, for the finer siftings contain double the amount of barytes (0·1 per cent) present in the virgin material. Also it may be noted that barytes commonly acts as a matrix in the Millstone Grit.[1]

6. The Budle Sands.

These were examined, as already mentioned, in greater detail than the other sands, and partly with a view to the isolation of particular minerals in a condition pure enough for analysis. From the data already given, it is evident that partial separation can be produced by sizing, and the effect of this is observable in the colour of the fractions, which lose the pink of the garnet and become grey, owing to increase in the proportion of zircon and rutile, as the grain size decreases.

The first stage in the separation is thus sizing, and, in subsequent operations the various grades were worked separately. Bromoform was commonly employed as heavy liquid, though swirling in Sonstadt solution (S.G. 3·18) and quick decantation proved useful in some cases. Separation with a bar-magnet gave two products, one highly magnetic, with strong polarity, the other not so magnetic and without marked polarity. Further magnetic treatment was with an electro-magnet, the current in the primary coil being capable of variation between 1·8 and 6 amperes. Finally, in some cases, where there was a marked difference in the roundness of grain, some concentration could be effected by allowing the material

[1] A. Gilligan, op. cit., 267.

to roll down a sloping sheet of paper, giving this at the same time a tapping or jigging motion. By the fractional application of these methods, a number of concentrates was obtained, some fairly pure, others still much mixed, which are described below.

An example of the fractional separation by the electromagnetic method may be given. The sample [K5, 6] of 80–100-mesh size, free from bar-magnetic minerals and consisting largely of garnet and opaque minerals, gave the following results on repeated fractionation with varying strengths of the electromagnet (as indicated by the strength of the current in the primary coil) :—

Current in primary coil (amperes).	Composition of Fractions.			
	abundant.	common.	rare.	very rare.
2·5	garnet.	opaque ore.	augite, rutile.	tourmaline.
3·8	garnet, opaque ore.	augite.	staurolite.	zircon, spinel, monazite.
4·5	opaque ore.	augite, monazite.	garnet, zircon, staurolite.	tourmaline, olivine (?).
5·5	Opaque ore. augite.	monazite, garnet.	staurolite, zircon, tourmaline.	sphene.
6·0	augite.	opaque ore.	monazite, spinel.	sphene, zircon. olivine (?)

The general order of decreasing magnetic susceptibility is thus :— garnet ; opaque ore ; augite and rutile ; monazite, tourmaline and staurolite ; zircon, spinel, sphene, and olivine (?).

Some of the best concentrates were as follows (own references in square brackets) :—

1. [16 Bα] Rich in monazite and one of the least magnetic. A count gave :—

monazite . .	55
opaque ore . .	17
zircon . . .	16
rutile . . .	11
augite . . .	1
	100

Apatite is very rare, and there is one grain of bluish-green garnet (?).

2. [16 B_1] Rich in zircon with rare monazite, a count of 1,500 grains giving :—

zircon . .	90·2
rutile . .	9·8
	100·0

Other fractions of this series gave (with rare monazite and apatite) :—

	[16 B_2]	[16 B_3]
zircon . . .	71	64
rutile . . .	24	30
opaque ore . .	5	6
	100	100

The monazite fraction [16 Bα] was withdrawn from this series electromagnetically at 6 amperes. The zircons are often " purple " with perfect crystal form and numerous inclusions. In their general characters they resemble those associated with the Lewisian rocks.

3. [17 C_1] This is the main rutile concentrate. A count of 1,800 grains gave :—

rutile (with some brookite) . .	59·4
zircon	39·3
apatite	1·3
	100·0

The tailings from this fraction [17 C_2] contained :—

rutile . . .	39
zircon . . .	14
apatite . . .	3
opaque ore . .	37
augite . . .	3
monazite . .	3
tourmaline . .	1
	100

4. [17 B_1] The bar-magnetic mineral with strong polarity (80-100 mesh).

It may be observed that the country around Budle is largely occupied by the Whin Sill, which, with its associated sedimentaries, crops out on the shore where the garnetiferous sands are found. There were thus *a priori* reasons for thinking that the magnetic minerals in the sands may be derived, in part at least, from the Whin Sill. To test this, the sample [17 B_1] has been analysed and the result (A, in table below) is compared with two analyses of the magnetic mineral prepared from the Whin Sill (B and C)[1] and also with Teall's analysis of a similar preparation made nearly fifty years ago.[2]

[1] J. A. Smythe, *Trans. Nat. Hist. Soc. Northumberland*, New Series, **1**, 16.
[2] J. J. H. Teall, *Quart. Journ. Geol. Soc.*, xl, 1884, 650.

	A	B	C	D
SiO_2	5·96	9·25	8·00	12·16
TiO_2	20·81	23·72	24·80	24·51
Al_2O_3	9·87	8·52	3·34	3·36
Fe_2O_3	42·13	28·58	32·20	24·70
FeO	16·85	23·51	24·93	26·54
MnO	n.d.	0·74	0·90	n.d.
MgO	0·48	0·72	0·90	1·49
CaO	2·52	3·12	2·40	4·40
Na_2O	n.d.	n.d.	0·36	n.d.
K_2O	n.d.	n.d.	0·19	n.d.
H_2O	0·75	n.d.	0·55	n.d.
P_2O_5	n.d.	0·08	0·20	n.d.
S	n.d.	n.d.	0·08	n.d.
Total	99·37	98·24	98·85	97·16

A = Magnetic mineral from Budle Sands.
B, C, D = Ditto from Whin Sill.

There is a general correspondence in the figures for the magnetic ore constituents (FeO, Fe_2O_3, TiO_2) in the three preparations from the Whin Sill, and their notable differences from those appertaining to the mineral from the Budle Sands leaves little doubt that the Whin Sill is not the main source of the magnetic minerals in the sands, though probably it has contributed to them in some degree.

5. [17 A] This series of concentrates contains the opaque ore minerals which do not possess polarity, are feebly attracted by a bar-magnet and strongly attracted by an electromagnet. Two of these have been analysed, viz. [17 A_1] 80-100 mesh, a jet-black mineral with chocolate streak, containing a little garnet, zircon and augite (the quantity available did not permit of a satisfactory analysis, but the results have comparative value and are given below), and [17 A_3], under 120 mesh, also black, with chocolate streak, and proved optically to be almost free from transparent minerals.

	[17 A_1]	[17 A_3]
SiO_2	5·25	2·00
TiO_2	25·68	3·72
Al_2O_3	20·97	18·78
Fe_2O_3	37·64	68·31
FeO	6·26	6·58
MgO	0·82	0·42
CaO	0·62	tr.
H_2O	n.d.	0·37
Total	97·24	100·18
S.G.	4·60	4·64

There is a great and unexpected difference in composition between these. The first rather resembles the bar-magnetic fraction [17 B_1], though here too there are notable differences in alumina, titania

and iron oxides. When [17 A_3] is crushed, the powder shows a predominance of red birefringent chips of haematite and some isotropic, yellowish to greenish-brown fragments, possibly of spinel. The presence of spinel is indicated by the high alumina content, and the presence of haematite is confirmed by the action of a strongly acid solution of stannous chloride, which, by its etching action on the lustrous surface of the grains, polished by attrition, reveals their blood-red colour ; this presently vanishes as the mineral passes into solution. Many attempts have been made to utilize this reaction in order to separate the haematite from the other minerals, especially spinel, but these have not been successful. There is not much point in quoting the analytical data, for they are difficult of interpretation, but it will suffice to say that they indicate considerable reduction in the quantity of ferric oxide in the solid residuals of reaction and thus confirm the presence of haematite.

The whole question of the nature of these iron and titanium minerals is clearly a complicated one and we hope to return to it at some future time. The indications at present are that they consist of those highly titaniferous constituents which, in the quartz-dolerites, are usually taken to be intergrowths of ilmenite and magnetite, associated with opaque rutile, haematite and possibly spinels allied to hercynite or picotite.

6. *The Garnets.*—Two good concentrates of these were prepared from the sands, one coarse (40–60 mesh) [16 A_1], the other fine (80–100 mesh) from [K $5_1$6], analyses of which are given below.

As in the case of the strongly magnetic minerals, it was thought that the origin of these garnets might be connected with the Whin Sill, being derived from the calcareous beds in contact with the intrusive rock. Though the published description of such garnets hardly lends support to this view, the point was tested by collecting a large number of chips from the contact-limestones of Budle and the Harkess Rocks, some of which are well marmorized, dissolving them in acid and examining the insoluble residue. This proved to be a rich haematitic mud, almost devoid of other minerals and failing to disclose, after suitable treatment, any grains of garnet.

So far as we know, there are no analyses of garnet from any source in Northumberland and it appeared to us an urgent matter to obtain satisfactory data for comparison. It was known to us, from conversation with the late Professor Lebour, that Sir Walter Trevelyan had made a collection of garnets from the Shaftoe Crags, some 60 or 70 years ago. Through the kindness of the Right Hon. Sir Charles Trevelyan, Bart., search was made through Sir Walter's old collection at Wallington and rewarded by the discovery of a small tube labelled, " Garnets, Shaftoe ".

Garnets can occasionally be seen in the grits of Shaftoe, though they are not easy to find. There is, however, a good deal of rain-wash on the outcrop of the grits and at the foot of the escarpment,

for the rock is lightly cemented with oxide of iron and weathers easily. This rainwash varies in size from rounded quartz pebbles, up to half an inch in diameter, to fine sand, usually carrying a fair amount of peaty matter. A large sample of all grades was collected and screened. The coarsest material was barren of heavy minerals. The grade between 10 and 30 mesh yielded 0·12 per cent of heavy minerals and contained, in 25 grams, 15 garnet grains, of the same order of size as those in the Trevelyan collection. The grade under 30 mesh contained 0·25 p.c. of heavy minerals, of which garnet and opaque ore were the most abundant; zircon and tourmaline were common, monazite and rutile rare, and brookite very rare.

To return to the Trevelyan collection, the tube contained some 700 garnet grains (along with 7 of tourmaline) and these had undoubtedly been collected laboriously, over a period of many years, from the rainwash of the Crags. The weight was 1·7 grams and the average diameter of the grains, assuming them to be spherical, which is approximately the case, is thus 1 mm. About half the sample has been preserved, the remainder being taken for analysis, the results of which, along with those of the two concentrates from the Budle sands, are given below.

Analyses of Garnets.

	Budle Sands.		Shaftoe Crags.
	Coarse	Fine	
SiO_2	37·30	36·40	38·20
TiO_2	0·93	1·12	0·67
Al_2O_3	21·79	21·41	25·12
Fe_2O_3	4·43	6·00	1·26
FeO	25·50	26·40	26·44
MnO	0·94	0·99	1·08
MgO	6·34	5·47	6·16
CaO	2·15	2·40	1·50
H_2O	n.d.	0·30	n.d.
Total	99·38	100·49	100·43
S.G.	4·08	4·00	4·05

Both of the Budle concentrates contained a little rutile and augite. As the Shaftoe material is free from rutile, it is evident that the titania in it is a constituent of the garnet and probably the same applies to most of the titania in the Budle garnets. The garnets are essentially of the almandine type and correspond to the composition :—

almandine . .	68·1
pyrope . .	22·2
andradite . .	7·1
spessartite . .	2·6
	100·0

The three analyses are strikingly similar and leave little doubt that the coarse and fine grades of garnet from Budle are of the same composition and origin, and further, that they are probably derived from Carboniferous sediments, whether directly or partly through the glacial drift must be left undecided until work of the character recently done on the Yorkshire drift [1] has been extended to Northumberland. All the garnets analysed are, in colour, various shades of pink.

7. Note on the Whin Sill as a Contributor to the Coastal Sands.

A good deal has been said in the foregoing as to the possibility of the Whin Sill contributing to the heavy sands and the evidence on the subject is not very clear. It is certain that the opaque ore minerals of the sands are not, in the main, derived from the Whin; but it is possible that the augite, characteristic of the Budle and Bamburgh concentrates, has its origin in that rock, though the absence of augite from the Longstone (to be mentioned shortly) must be noted in this connexion.

The wider question of the contribution made by the Whin Sill to the coast sands generally has naturally attracted our attention, since it occupies the coast for many miles in the northern part of the county. It can be definitely stated that there are no whin sands, in the sense that grains of whin, or mineral derived from it, are their chief constituent. Where the whin surface dips at a low angle to the sea and there is no blown sand, as along the wave-swept stretch from Dunstanburgh to Cullernose Point, there are no pebbles or sand except in small sheltered coves, and blocks of loose rock, about high water level, are angular. In the coves, whin pebbles are well rounded and seldom below 3 inches in diameter; any sand there may be is largely siliceous and shelly and invariably contains garnet, but it is accompanied by sedimentary rocks and igneous erratics of glacial origin.

Such a cove is that by Cushat Steel, and a sample of the sand gave :—

light crop	shell	35	
	quartz	63	
heavy crop		2	whin grains with opaque ore and garnet.
		100	

The characteristic waste derived from cliffs of the Whin Sill is in the form of large, rounded boulders, 1 to 3 feet in diameter. They are finely shown at Football Hole, near Newton, and north of Castle Point; in the latter case, they extend half a mile north of the outcrop and are eventually covered by the sands of Embleton

[1] A. Raistrick, Geol. Mag., LXVI, 1929, 237.

Bay, whilst still of large size. Where whin in the cliff gives place to sedimentaries, as at Cullernose Point, the whin pebbles are drifted in great profusion over the sedimentaries, and presently there is a complete reversal in the proportions of the two rocks in the coarser pebbles and sand. Thus, 400 yards south of Cullernose Point, the foreshore pebbles are largely of whin, while the sand, (under 30 mesh) at the foot of the cliff contains 97·4 per cent of light minerals (chiefly quartz) and only 2·6 per cent of heavy material rich in whin grains.

The Farne Islands are interesting in this connexion, since they are so far from the mainland that blown sand does not introduce complications, though doubtless sand drifted by currents along the sea-bottom and thrown up in storms is a disturbing factor. Of this we have no evidence.

Two of the islands were studied, the Inner Farne, nearest to the land (1½ miles) and the Longstone, furthest from the land (4 miles). In the former, whin is predominant, but there is a small patch of low-lying sedimentaries and a little boulder-clay. There is one small sandy beach, the examination of which gave :—

light crop	shell	57	
	quartz	41	subangular mostly, turbid with inclusions, with rare microcline.
heavy crop		2	whin, opaque ore and garnet abundant, brown to purple augite common, zircon rare.
		100	

The Longstone is entirely composed of whin. The largest patch of sand gave :—

light crop	shell	94·5	
	quartz	4·9	contained a little microcline.
heavy crop		0·6	mainly whin, and opaque ore. No garnet or augite.
		100·0	

There is evidence from these results that the Whin Sill contributes but little to the finer sands in its neighbourhood, and that mostly in the form of grains of the rock. The small size and interlocking structure of the constituents prevent it from forming a mineral sand, and its susceptibility to chemical change and possibly, its mechanical weakness under shore conditions when finely comminuted, ensure its rapid degradation to a fine mud. It may be noted, too, that garnet fails as a constituent of the coastal sands only in the complete absence of sedimentary rocks, boulder-clay and blown sand.

The Type-Specimen of *Orthoceras attenuatum* Sowerby.

By F. R. Cowper Reed, Sc.D.

A SPECIMEN in the Ludlow Museum, which appears to be the lost type of Sowerby's species *Orthoceras attenuatum* figured in Murchison's *Silurian System*, plate 13, fig. 25, p. 632, from the Wenlock Shale of the "banks of the Onny River, near Stretford Bridge", has been recognized by Mr. T. D. La Touche in rearranging and cataloguing the collection of local fossils. Owing to the fact that the large piece of rock (D. b. 49 in La Touche's catalogue) on which it occurs was fastened down to a tablet so as to expose only another specimen of a smooth and different species of *Orthoceras*, it had been completely hidden from view, as it was on the lower side. The specimen not only agrees in size, general characters, and rate of tapering with Sowerby's figure (though the annulations are sharper and narrower than there indicated), but it was also collected by Dr. Lloyd, as was the type, as stated by Murchison. The horizon (Wenlock Shale) is recorded on the existing label, but not the locality. However, Mr. La Touche, from his intimate knowledge of the rocks of the district, considers that the locality may well be that given by Murchison. A small portion of the upper end of the shell is now missing, corresponding to the imperfect non-annulated piece shown in the figure, but it seems to have projected freely out of the matrix, so it may easily have been broken off. Otherwise the specimen is in the same good condition as when Sowerby drew his figure, and we can have scarcely any hesitation in identifying it on the strength of the above evidence.

No description of its specific characters was given by its founder, and Blake (*Brit. Foss. Ceph.*, i, 1882, pp. 89, 91), who had only the figure by which to judge, was of the opinion that it was possibly referable to *O. annulatum*, but he pointed out that if it proved to be a new species another specific name must be given it, as *attenuatum* was preoccupied. From an examination of this specimen in the Ludlow Museum, the following diagnosis may be here given: Shell straight, very slender, much elongated, slowly tapering at about 1 in 12, annulated by numerous (60–65) regular direct equidistant narrow rounded rings, separated by concave interspaces, 2–3 times as wide, and ornamented with fine sublamellose, slightly undulating concentric lines rather widely spaced on upper portion of shell, but becoming more numerous and closer together towards apical end, with fine concentric striae between them. Septa and siphuncle not visible.

Dimensions.—

Length, 97–100 mm.

Diameter at upper end, 8 mm.

Affinities.—The species may be referred to the genus *Dawsonoceras*, and is apparently allied to *O. perelegans* Salt. (pars) (*Mem. Geol. Surv.*, vol. ii, p. 354, pl. 13, figs. 2, 3, non 4) as restricted by Blake (op. cit., p. 97), who considered that Salter's species might be inseparable from O. *tracheale* Sow. (*Silur. Syst.*, p. 604, pl. iii, fig. 9b), though we may doubt this, for in *O. perelegans* the rings are slightly oblique and undulate. We may also draw attention to its resemblance in many respects to *O. elegantulum* Dawson (McLearn, *Mem. Geol. Surv. Canada*, No. 137, 1924, p. 156, pl. xxiv, figs. 1–3, pl. xxix, fig. 7) from the Stonehouse Formation of Arisaig, Nova Scotia, which has been regarded as allied to *O. perelegans*, but it is probably a distinct species. No other example of *O. attenuatum* is preserved in the Ludlow Museum, and I have not seen any which can be considered identical in any other collection.

Note on Rocks from the Sahara collected by Captain D. R. G. Cameron.

By Ethel D. Currie, B.Sc., Ph.D., F.G.S.

THE collection of rocks from the Sahara to be discussed was made by Captain D. R. G. Cameron, of the Royal Scots, during a journey across the Sahara from Kano to Algeria. The journey is described by Captain Cameron in his book *A Saharan Venture* (1928) and in a paper published in the *Geographical Journal* (lxxi, 1928, 538–59). The specimens were not collected in situ, which reduces their value somewhat. When one considers, however, that the collecting area is desert country where outcrops are comparatively scarce it is apparent that conclusions based on pebbles are not without value.

The specimens were collected in five different areas:—

(A) A small area in the neighbourhood of Tin Wana or Tin Nouana.

(B) A small area in the neighbourhood of Iferuan.

(C) A long narrow area extending in a N.N.W—S.S.E. direction, from south-west of Tadent to Tadera.

(D) A long narrow area between Fort Charlet and Fort Polignac.

(E) A long narrow area between Fort Polignac and Fort Flatters forming an arc to the S.W.

In 1927, Mr. F. R. Rodd made a collection of rocks and fossils in Air, South Central Sahara. In a paper on this collection by Prof. J. W. Gregory and myself (*Q.J.G.S.*, lxxxvi, 1930, 399–403) a map was published showing the distribution so far as known of the Pre-Palaeozoic, Turonian, and Pre-Turonian Cretaceous in the areas traversed by Mr. Rodd. This map includes the above areas, A and B, and the specimens collected by Captain Cameron bear out our previous conclusions regarding them. At A Captain Cameron

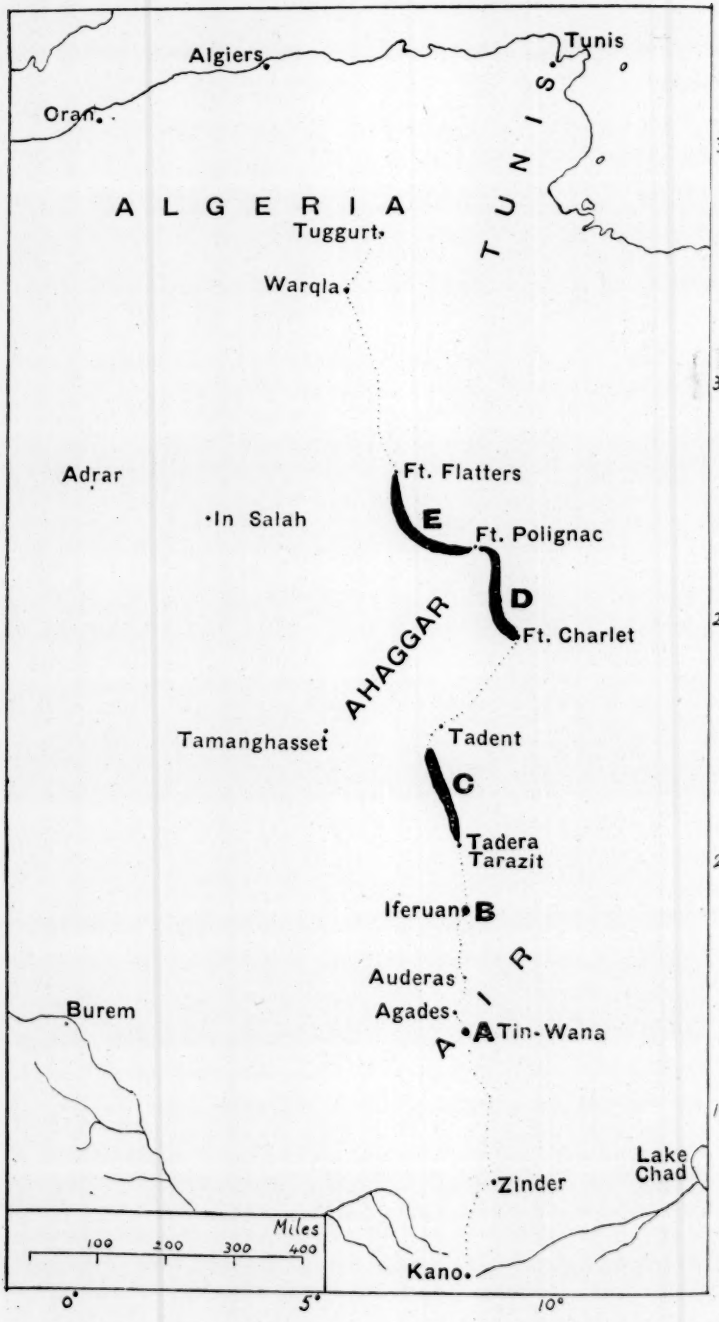

FIG. 1.—Sketch-map to show the areas A, B, C, D, E; after Captain Cameron's route map.

found quartz pebbles, liver-coloured friable sandstone, and a limonitic quartzose siltstone. A specimen identified by Dr. Tyrrell as a recrystallized mylonite from this locality gives no indication as to age, but the other specimens are consistent with the occurrence of the Pre-Turonian Cretaceous in the area of Tin Wana. From B biotite-schist, granite and granodiorite, and felspar-porphyries show the occurrence of the Pre-Palaeozoic rocks. A grit and a limonitic siltstone point to the probable proximity of the Pre-Turonian Cretaceous. The occurrence of volcanic rocks is indicated by specimens of rhyolite and glassy basalt.

At C Captain Cameron obtained specimens of green chalcedony, red sandstone, white and violet sandy shale, a quartz pebble, a flint nodule, and a specimen of quartz-breccia. This association seems to indicate an area of the Pre-Turonian Cretaceous, while the occurrence of a pebble of gneiss and fragments of felspar suggest the occurrence of Pre-Palaeozoic rocks at a distance.

From D also there is evidence of the Pre-Turonian Cretaceous as shown by the specimens of red, white, and shaly sandstone, grit, and ferruginous quartzose siltstone. A piece of limestone, although unfossiliferous, may belong to the Turonian.

The rocks from locality E suggest the occurrence of the three rock series, the Pre-Palaeozoic, the Pre-Turonian Cretaceous, and the Turonian. The rocks are biotite-schist and quartzite (Pre-Palaeozoic); sandstones, quartz-fragments, fossil wood and chalcedony (Pre-Turonian Cretaceous), and limestones (Turonian). Dr. Tyrrell has indentified a rock from this area as an epidosite (albite, epidote, and quartz-rock).

The collection includes gypsum from N. of Fort Flatters, which is probably also from the Pre-Turonian Cretaceous.

It is not possible to draw a map showing the distribution of the different rock series, but it is of interest to compare the above conclusions with the map of Conrad Kilian in the paper " Essai de la Synthèse de la Géologie du Sahara Sud Constantinois et du Sahara Central ", *Congrès Géol. Internat.*, 13, 2. This map includes the areas D and E and in it the southern part of D lies in an area marked pre-Cambrian, while the northern part of D is on an area of Devono-Silurian rocks (Tassilis externes and internes), which include graptolitic shales (and possibly Cambrian rocks also). Then again the area E extends along areas of Silurian, Devonian, and Carboniferous rocks (Tassilis externes and Pre-Tassiliens).

The interest of Captain Cameron's collection lies in its bearing on the Cretaceous Sea of the Central Sahara which extended N.–S. from the Tethys or Mediterranean to the Angola Gulf. In the south, Cretaceous rocks are known in Angola, in Nigeria between Lake Chad and the Lower Niger and in Tegama. The recent collection of Mr. F. R. Rodd showed that Cretaceous rocks occur as far north as the flanks of the Tarazit Massif. In the northern Sahara Cretaceous rocks have been proved as far south as Tidikelt

and Temassinin or Fort Flatters (*Handb. Reg. Geol.*, Afrique Occid., p. 29 and map). Captain Cameron's localities C, D, E lie between these northern and southern areas of Cretaceous rocks and his collection (if my conclusions regarding the age of his specimens are correct) serves to link the two across an area from which so far only Palaeozoic rocks (with small patches of Pre-Palaeozoic and volcanic rocks) are recorded. His localities lie on the eastern side of Ahaggar and his collection therefore affords evidence that the Cretaceous Sea extended along that side of the massif.

In the paper on Mr. F. R. Rodd's collection from Aïr recently published (loc. cit., p. 403) it was suggested that the Cretaceous Sea probably extended along the western side of Ahaggar. A western extension is not disproved by Captain Cameron's collection. It is probable that Ahaggar was surrounded by the Cretaceous Sea as put forward by Hennig in 1929 (*Centralblatt für Miner.*, etc., B, p. 277). His sketch-map of the distribution of land and sea in the Turonian shows Ahaggar as an island in the Turonian Sea.

I am indebted to Prof. J. W. Gregory for reading this note in manuscript and for advice and criticism. I am obliged to Dr. G. W. Tyrrell also for his identifications of some of the rock sections.

The Geology of Jebel Usdum, Dead Sea.

By B. K. N. Wyllie, Geologist, Anglo-Persian Oil Company.

(Published by permission of the Anglo-Persian Oil Company.)

(PLATE XIII.)

Summary.

The salt of Jebel Usdum is not a product of the Pleistocene Dead Sea, nor of the lake which preceded it (in ? Pliocene time), the waters of which were fresh for a long period and deposited sediments, with a maximum thickness of 1,000 feet or more, which are younger than the salt.

Its origin is probably to be sought in the Mesozoic or possibly in the Palaeozoic. The Dead Sea region is characterized by sedimentation of a Nubian Sandstone type from Cambrian to Middle Cretaceous time. Wedges of marine strata indicate marine incursions in parts of the Cambrian, Triassic, and Jurassic. It is thought that at one or other of these periods desiccation of lagoons along a desert shore may have caused local accumulation of salt. Further, the Cenomanian strata in southern Transjordan include a persistent gypsum horizon; and in southern Palestine the Cenomanian limestones are in places dolomitic.

The salt has reached its present position by intrusion. It has pierced, buckled, and raised the sediments of the earlier Dead Sea. Uplift has continued until quite recent time, and may now be in progress.

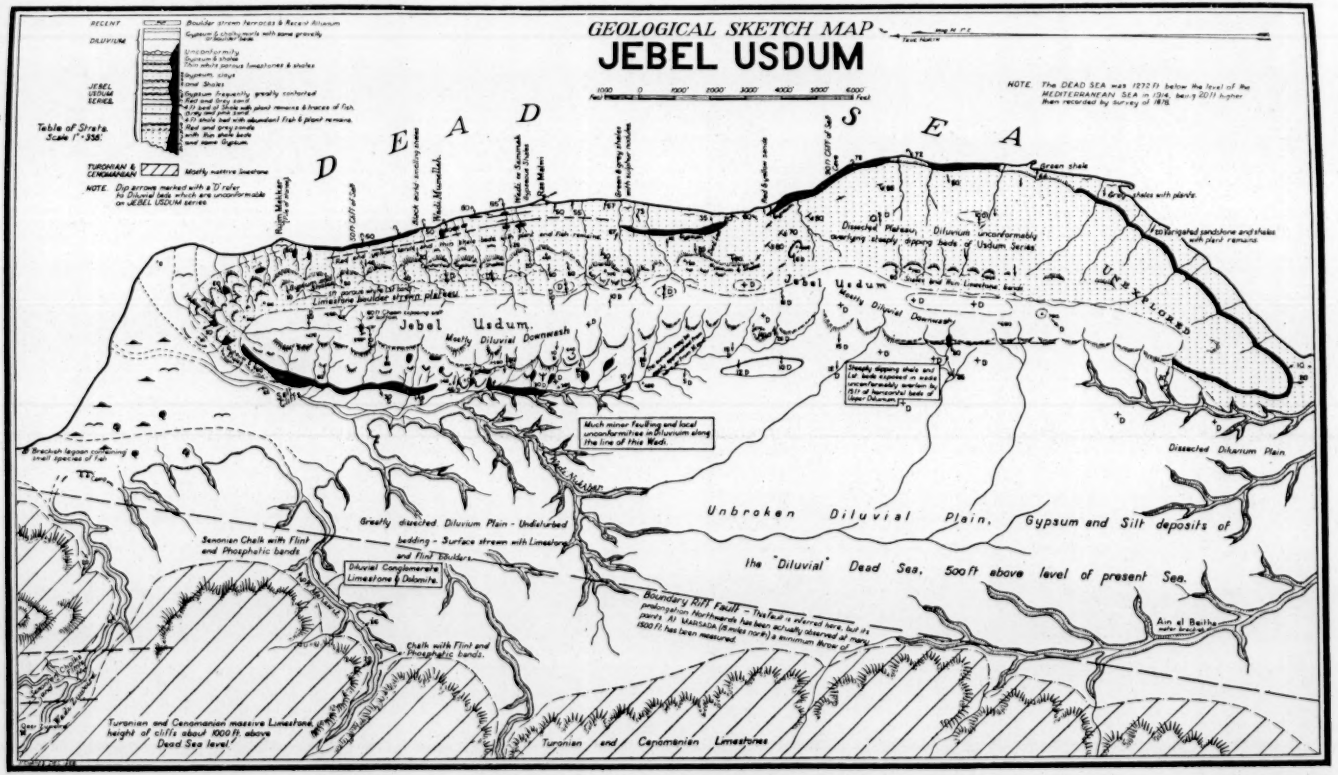

FIG. 1.—Geological sketch-map of Jebel Usdum, by G. M. Lees, 1923.

The present note merely announces the main results of a hurried examination. Opportunity for a detailed study, such as the locality deserves, has not arisen. In the latter part of 1922, the writer, with K. A. Campbell and George M. Lees, had an opportunity of spending several days in the neighbourhood of Jebel Usdum, a remarkable hill which borders the shallow southern end of the Dead Sea and rises approximately 700 feet above its surface, standing, in the words of Lartet, " comme un hors d'œuvre au milieu de la plaine " (Plate XIII).

Dr. Lees made a plane-table sketch of the region, while Mr. Campbell and the writer studied and measured several sections. The combined observations are outlined in Fig. 1. The geology was found to be much more complicated than had been supposed; but the time available did not permit of a full and adequate study, nor does opportunity for such a study seem probable in the future. The following note is therefore prepared in order to cover one of the gaps in the geological literature concerning Palestine, without offering more than a temporary filling.

Strata.

Diluvium.—The dissected plain which separates Jebel Usdum from the mountains on the west shows several hundred feet of horizontal strata—gypsum and gypseous marls, silts, and sands, which pass into conglomerates in the neighbourhood of the western Dead Sea scarp. The same formation, in many places tilted, caps large areas on the crest of the jebel. This is attributed to sedimentation and chemical precipitation in a Pleistocene lake, the level of which rose nearly 500 feet higher than that of the present Dead Sea.

Jebel Usdum Series.—The Diluvium on the hilltop lies in many places unconformably on steeply dipping strata which were difficult to arrange in any order. The sequence finally adopted, which may be regarded as tentative, allocates to the base of the series some 500 feet of soft grey, yellow, and pinkish-red sands, medium- to fine-grained, with a few thin bands of grit and lenses of rounded, chert-gravel. At what appeared to be the lowest exposed horizon these sands included a thin bed of breccia containing angular lumps of limestone and chert. The lower part of the sands includes also a 3 feet band of grey shale and limestone containing fish-scales. Near the top there are two 4 feet bands of dark papery shales from which fish- and plant-impressions were collected. These were shown to Sir A. Smith Woodward, who identified the fish as a species of Mugil or freshwater mullet, but was unable to assign any age to them.

The upper part of the Jebel Usdum Series consists of shales and gypsum, with some thin limestone-bands, and some dark shales also containing plant-remains. This part of the sequence was not

Jebel Usdum from North-West.

[*To face p.* 368.

found exposed in clean-cut sections, and its thickness was not determined. The interpretation adopted at the time of the survey assigned to it some 500–600 feet. The gypsum is chiefly in the form of thinly-laminated, and frequently puckered, bands; but both these bands and the intervening shales contain many well-shaped crystals of selenite.

The Dead Sea shore shows several clean sections cut in steeply-dipping beds of this gypseo-argillaceous division. The strata consist of greenish marl, with thin layers of soft gypsum and nodules of sulphur, commonly intensely puckered and traversed by many minute faults. Some recrystallization of the gypsum was observed here also. Apart from disturbance and recrystallization, there is a close lithologic resemblance between these beds and the typical Diluvium, as seen for example in the Jordan Valley south of Jericho; both are essentially alternations of fine sediments and chemical precipitates.

Rock-Salt.—The most spectacular outcrop of salt is on the Dead Sea shore near the south end of Jebel Usdum, where it forms a cliff some 90 feet high, extending for several hundred yards and pierced by a tunnel-like cave. It is disposed in massive bands, inclined at a high angle, sometimes separated by thin layers of clay and gypsum, more often defined by differences of grain-size and colour. This apparent bedding is truncated on top by a horizontal layer of argillaceous material with gypsum crystals—a formation not understood, but thought to be a kind of cap-rock. The salt is a medium-grained compact crystalline aggregate, white to grey, in places black, with a few pegmatite-like veins consisting of large salt-cubes.

Fig. 2.—Sketch-section (not to scale) through salt-mass at salt-cave, Jebel Usdum.

Figure 2 shows roughly the relation of this salt-mass to the strata already described. Farther north, at Lot's Wife (wrongly referred to on the map (Fig. 1) as Bint Lut),[1] the salt appears as shown in Fig. 3.

[1] A stronger tradition seems to attach Lot's name to pinnacles of calc-sinter which have been formed along the eastern rift-fault, on the Transjordan side, some distance south of Wadi Mojib. These are called Mart Lut, Bint Lut, and Kelb Lut (Lot's Wife, Daughter, and Dog).

Salt was seen at many other places around the edge of Jebel Usdum, and in several pot-holes on its slopes. Most of the exposures are obscured by mingling with mud or sand from the beds with which the salt comes in contact, so that banding or stratification can not be observed. At one place angular fragments of gypsum and shale were found imbedded in salt, forming a salt-shale-gypsum breccia.

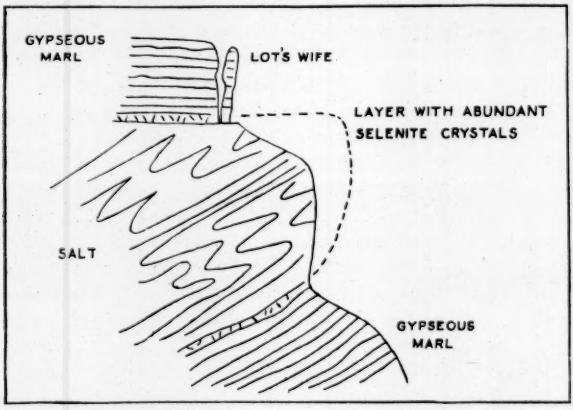

Fig. 3.—Sketch-section at Lot's Wife, Jebel Usdum.

Structure.

It is regarded as certain that the salt is older than any of the strata described, and that it has reached its present position, in contact with all stages of the Jebel Usdum Series and with Diluvial beds, by intrusion as a semi-fluid.

The Jebel Usdum Series on the Dead Sea side of the hill seems to be disposed in a sharp anticline, overturned towards the east and in many places broken by longitudinal faults. Tongues and lobes of intrusive salt occur erratically.

There are some indications that the eastern side of the hill-top, at the northern end, is occupied by a sharp syncline, filled with beds of the Jebel Usdum Series, across the truncated ends of which lies horizontal Diluvium.

The western half of the north end of the hill is Diluvium-covered; but salt appears in sink-holes and in great cliff-sections on the western margin. Possibly this represents another anticlinal structure, with a solid salt-core, from which the Jebel Usdum beds have been eroded in pre-Diluvial time; or possibly the cover of Jebel Usdum beds has been simply ruptured and pushed aside by uprising salt.

No cross-section is ventured, as none can be constructed on the available evidence without involving an excessive amount of imagination.

The presence of coarse Cretaceous limestone detritus on the

hill-top shows that uplift has continued in very recent time, as this was no doubt emplaced by the wadis which now swing towards the north on leaving the scarp.

Age of the Salt.

The older theory that the salt belongs to the Diluvium must be abandoned, because it is in contact with the oldest visible beds of the Jebel Usdum Series, which are unconformably overlain by the Diluvium.

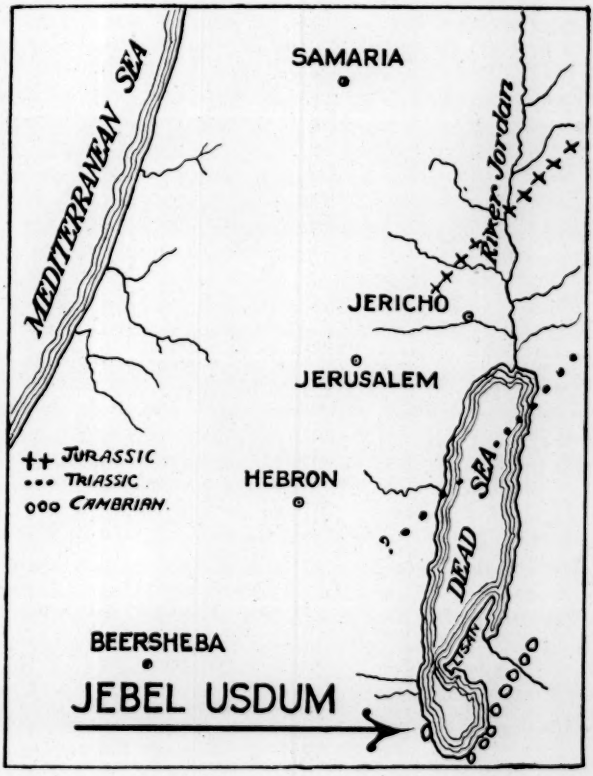

Fig. 4.—Position of Jebel Usdum and trend of ancient shore lines.

Discrimination of the Jebel Usdum Series adds a whole chapter to the history of the Dead Sea—a chapter during which arenaceous sediments, followed by argillaceous beds and chemical precipitates, accumulated to a thickness of 1,000 feet or more; were broken, buckled, and elevated by intrusion of a great mass of salt; and thereafter eroded and covered by a new series of sediments characterized again by plentiful chemical precipitates, which in

turn have been elevated and to some extent disturbed by further movement of the salt.

It cannot very well be argued that the salt represents an early product of the lake which deposited the Jebel Usdum Series, because the lower part of that series contains a freshwater fauna. Moreover, the thickness of the Jebel Usdum Series alone seems quite inadequate to supply the pressure necessary to cause intrusion of salt. On the other hand, older potential sources of salt can readily be indicated. A prominent gypsum horizon divides the Cenomanian strata on the Transjordan side of the Dead Sea; and as some of the Cenomanian limestones south of Ain Jidi are dolomitic, they might have been deposited in concentrated waters. Further, the region of the Dead Sea contains the traces of a remarkable number of ancient shore lines (Fig. 4). A great mass of pre-Cambrian conglomerates is seen at the south-east corner. Fossiliferous Cambrian [1] strata are found in the same region, but seem to be absent farther east. The Nubian Sandstone a short distance north of the Lisan peninsula has yielded fossil plants that may be Triassic or Jurassic. At the north-east corner of the Dead Sea [2] the Nubian Sandstone contains limestones and shales, with marine Triassic fossils, which are entirely absent only a few hundred yards farther east. Marine Jurassic rocks are found in the Wadi Jabbok [3] but are replaced by Nubian Sandstone farther south.

It is probable that from Cambrian to Middle Cretaceous times the sea has repeatedly covered this region without advancing very much farther to the east. It is therefore quite possible that salt may locally have been deposited in large quantities in one or more periods, as the persistence of the Nubian Sandstone facies may be regarded as evidence that the climate has been more or less arid since Cambrian times.

Apart from Jebel Usdum, however, no sure evidence of salt-intrusion was found. On the left bank of the Jordan, about 17 miles north of the Dead Sea, a strong updoming of freshwater sands and marls from beneath a cover of Diluvium was observed. The core of this dome, however, showed several protuberances of basalt, suggestive of laccolithic uplift.

[1] W. B. R. King, "Cambrian Fossils from the Dead Sea": GEOL. MAG., LX, 1923, 507–14.

[2] L. R. Cox, "A Triassic Fauna from the Jordan Valley": *Ann. and Mag. Nat. Hist.*, xiv, 1924, 52–96. Idem, "A Bajocian-Bathonian Outcrop in the Jordan Valley": ibid., xv, 1925, 169–81.

[3] H. Muir-Wood, "Jurassic Brachiopoda from the Jordan Valley": ibid., xv, 1925, 181–92. The collections described in these papers by King, Cox, and Muir-Wood were all made by the writer and his colleagues, K. A. Campbell and George M. Lees.

REVIEWS.

STATISTISCH-BIOSTRATIGRAPHISCHE UNTERSUCHUNGEN AN MITTEL-JURASSISCHEN AMMONITEN ÜBER ARTBEGRIFF UND STAMMESENTWICKLUNG. Von ROLAND BRINKMANN. *Abh. der Gesellsch. Wissensch. zu Göttingen*, Math.-Phys. Kl., N.F., xiii, 3, 1929.

OF all the formations of the English Jurassic System the Oxford Clay has received the least attention in recent years. Since the appearance in 1895 of H. B. Woodward's great memoir on the Jurassic Rocks of Britain, only three slender papers have been published on the subject; an admittedly arm-chair study of the "Kellaways", or time equivalent of the Oxford Clay, on the Yorkshire coast, by the late S. S. Buckman, and two small but valuable papers on the zonal sequence in Buckinghamshire and Bedfordshire and around Peterborough, by Professor A. Morley Davies and Dr. E. Neaverson respectively. In addition some work has been carried on in the Oxford district, but has only in part been published, while Buckman from time to time in his last years brought out photographs of Oxford Clay ammonites along with those from other parts of the Jurassic in his *Type Ammonites*.

In 1926 Dr. Roland Brinkmann obtained a grant from the Gesellschaft der Wissenschaften in Göttingen, and with Herr G. Richter spent two months at Peterborough studying and collecting ammonites. More than three thousand specimens were collected in situ, and have been dealt with in this report and in a monograph of the Kosmoceratès which followed (see a short review of the latter, GEOL. MAG., LXVI, 1929, 287). The report contains 250 pages, with fifty diagrams and 129 tables, while the monograph was issued as a separate part of the *Abhandlungen*. Never before has a group of ammonites been subjected to such a searching statistical analysis based on such large quantities of individuals, and the results are worthy of much closer attention than they have hitherto received in this country.

Operations were confined to three claypits, those of the London Brick Co., south of Fletton, and of the same company between Kingsdyke and Whittlesey, and that of the Itter Brick Works in Kingsdyke. These three exposures were found to overlap sufficiently to provide a continuous section measuring 13 metres (43 feet), which was divided up into centimetres for purposes of collecting and recording, thus affording 1,300 horizons. The section covered the seven zones *conlaxatum-lamberti* inclusive, of Dr. Neaverson's table (1925), belonging to the Kosmoceratan and the early part of the Vertumniceratan ages.

Study was concentrated on the abundant genus *Kosmoceras*, and within the genus on four groups regarded by Brinkmann as natural subgenera ; *Kosmoceras sensu stricto* and Buckman's genera *Zugokosmoceras*, *Anakosmoceras*, and *Spinikosmoceras*. Within these subgenera Brinkmann recognized thirteen species, those belonging to the several subgenera living and evolving independently side by side. The great reduction in the number of species results from the rational method of regarding the subgenus as an evolutionary chain, in which the species are links of arbitrarily chosen but uniform length. Before reaching and after passing the stage represented by a type specimen, the evolving stock passed through more or less intermediate stages, which are designated *anterior* or *posterior* subspecies according to the species which they most nearly resemble in either direction. To express this Brinkmann uses trinomial and quadrinomial nomenclature. The typical form is expressed by repeating the specific name : thus *Kosmoceras* (*Anakosmoceras*) *gulielmii gulielmii* (Sow.), the earlier or later stages near to the type form being distinguished thus: *K.* (*A.*) *gulielmii anterior* Brink., etc. The reintroduction of trinomial nomenclature might be avoided in two ways. Either the designations *anterior*, *posterior*, and others such as *duplicosta*, could be written as varieties in the ordinary way, thus : *K.* (*A*) *gulielmii* (Sow.) var. *posterior* Brinkmann ; or Buckman's solution could be followed, namely the shifting upward of the values of the whole classificatory system, so that *Kosmoceras* becomes *Kosmoceratidae*, *Anakosmoceras* becomes the genus, *Gulielmites* the subgenus (Buckman considered it a genus and even in a different family, *Gulielmiceratidae*), and *posterior*, *anterior*, etc., the species. This solution has the great disadvantage of involving the multiplication of names to an almost indefinite extent. If var. *anterior* and var. *posterior* be regarded as recurring variations in different stocks there is no harm in using the names over and over again, and they always convey an equivalent meaning. Such a system of designating parallel variations among the Lamellibranchia and Gastropoda has been in use for a long time. On the other hand, if the subspecies or varieties be regarded as species, many new names have to be coined. Moreover, the raising of all Brinkmann's species to even subgeneric rank involves an unduly narrow interpretation of a genus, inconsistent with common usage in the mollusca. An overwhelming case is made out by Brinkmann against what has come to be called the Buckman method of indefinitely multiplying generic names which neither betray any affinities nor necessarily possess any phylogenetic significance. It is only with his method of overcoming the difficulty that all will not find themselves in agreement. *En passant* it may be remarked that the principle of choosing neotypes for some English species, such as *K. duncani* (Sowerby) out of foreign material does not seem a very happy one.

The characters on which the statistical work is based are those

ordinarily taken into account in studying the ammonites—proportions, coiling, and ornament[1]—but the interpretation of them is elaborated and exhibited in such a way as " to determine as accurately as possible the modifications undergone by the animals with the passage of time ". In spite of the crushing which most of the shells have suffered, the percentage of error in the measurements is believed to be too insignificant as compared with individual variation to interfere with accurate definition of the phases reached at successive levels. The figures defining each phase are arrived at by taking the average of a large number of individuals. Then the percentages of variation in the characters at successive levels are compared, and so the average rate of evolution per vertical unit thickness of clay is determined. A more serious potential source of error is involved in the assumption that the dead shells entombed in any particular bed are a truly representative sample of the population at a given time. Brinkmann recognizes this, but does not consider that the assumption is so risky as to jeopardize the value of the results.

It is found that evolution proceeded both steadily and in jumps. The jumps or gaps coincide with the thin beds of whole and comminuted shells which recur at intervals through the clay. A lithological study of these shell-beds supports the conclusion that they represent long pauses or breaks in the continuity of sedimentation, which apparently proceeded in cycles governed by widespread tectonic (epeirogenic) disturbances.

The shell-beds are explained as concentrations produced by increased current-action during shallowing of the sea. They are of two sorts, called by Brinkmann Dachbänke and Sohlbänke (perhaps best translated as roof-beds and bottom-beds), according to their position at the top or at the base of a block of normal sediment. The roof-beds were formed immediately before one of the breaks in sedimentation, the bottom-beds immediately after. Another feature of the shell-beds is the appearance in them of a rich fauna of lamellibranchs. This contrasts them further with the intervening clays, in which the entombed animals are exclusively plankton and nekton (ammonites, belemnites, and vertebrates). Brinkmann interprets this difference by supposing that the clays were deposited upon a stagnant bottom in water poor in oxygen and rich in H_2S, anaerobic conditions in which benthos could not live. The shallowing and increased current-action which produced the shell-beds he considers brought with them better aeration, leading to conditions more favourable to the bottom-dwelling lamellibranchs.

No one interested in the processes of sedimentation, or in either evolution or systematy, can afford to overlook Brinkmann's work. It may seem to those not blessed with a superfluity of leisure, however, that the results would have lost nothing by being compressed into

[1] Suture lines are not preserved and so had to be disregarded.

two-thirds of the space. There is some repetition, but on the whole the ideas are lucidly set forth, with a refreshing scarcity of the terrible words which make some of our English work on ammonites unintelligible even to Englishmen, should they not be provided with a glossary. The author is certainly to be congratulated on accomplishing an enterprising and arduous undertaking with ingenuity, patience, and judgment. However much some may disagree with the wholesale " lumping " of the Kosmocerates in the ensuing monograph, it is at any rate clear that the conclusions have been arrived at after a closer study than the subject has received at any other hands. Although this notice is much overdue it will not have failed in its purpose if it directs to the work some of the wider attention which it deserves.

W. J. A.

THE GEOLOGY OF MALAYA. By J. B. SCRIVENOR. xx + 217 pp., with 33 figures and a coloured geological map. Macmillan, London, 1931. Price, 16*s*.

AFTER a short period on the Geological Survey in this country, Mr. Scrivenor has spent nearly thirty strenuous years in Malaya, and at or about the date of the appearance of this review he is due to retire. For several years he *was* the Geological Survey of the Federated Malay States, and for the rest of the time he has been the chief of what is still only a small staff. Nevertheless during his reign it has been found possible to publish a geological map of a country roughly 500 miles long. This is a remarkable record, because only those who are personally acquainted with the difficulties of field work in tropical jungle country are really in a position to appreciate the magnitude of the task.

The present writer felt some slight diffidence in undertaking the review of this book, because it so happened that he was involved, to a slight extent, in a geological controversy which variegated Mr. Scrivenor's official career, but this controversy really concerned only matters of detail in a limited area, and is very briefly mentioned in the present work. The questions at issue happened to be of considerable economic importance, but have little bearing on the general geology of the Peninsula, which is the subject of the book. On the main lines of this there is no dispute. It is agreed on all hands that the country consists of rocks ranging from somewhere in the Carboniferous to the Rhaetic, with enormous granitic intrusions of Jurassic or Lower Cretaceous age, and very little else. Notably, in strong contrast

to Sumatra and Java, there are no Tertiary or Recent volcanics. So far as structure is concerned, the conspicuous feature is a series of well-marked anticlines, called *coulisses* by Mr. Scrivenor, in agreement with the geologists of the Netherlands East Indies. These anticlines are not exactly parallel to the axis of the peninsula, but are arranged *en échelon* with a nearly north and south strike. They have served to determine the localization of the enormous elongated granite bathyliths, which form so striking a feature of the general geology, and have also been responsible for the rich tin mineralization, which is also continued into the Dutch islands of Banka, Billiton and Singkep. Everybody knows that this Malayan region is the world's greatest tin producer.

It is unfortunate that throughout the country, fossils are very scarce; hence considerable doubt still prevails as to the exact age of the Carboniferous and Triassic rocks; the evidence, such as it is, is also somewhat contradictory. So far as the present writer is aware, no exclusively Permian fossil has ever been identified, although a very rich Permian fauna has been described by the Dutch geologists from Timor. Further, it is uncertain whether the limestones of Perak are succeeded conformably by the Trias or not. The present writer has seen sections apparently showing complete conformity, and others, perhaps more commonly, with a conspicuous break. The great difficulty in this matter is the extensive underground solution of the limestone. In any case the whole development affords a violent contrast to the normal Gondwanaland facies. It should be noted that in the southern half of the Peninsula, the Carboniferous rocks, the Raub Series, are much less calcareous, and there are no limestone hills south of Kuala Lumpur. The Trias, however, maintains the same character right down into the Dutch islands, and around Singapore it is intensely folded and compressed. The section on Pulau Bukum, just outside the harbour, figured on p. 107, is very remarkable. The present writer has the honour of acting as a scale in this picture, which by the way, is very badly reproduced.

A matter of considerable interest that remains unsettled is the relation of the Mergui and Moulmein series of Burma to the Carboniferous-Trias of Malaya. The Mergui series shows resemblances both to the rocks below the limestones in northern Malaya (Langkawi Is.) and to the Trias further south, while from photographs it appears that there are in Burma limestone hills very like those of Malaya. The Mergui-Moulmein problem in Burma seems to be rather like the limestone-schist controversy in Kinta, alluded to earlier in this review.

With regard to the later history of the area, Mr. Scrivenor gives a very interesting discussion of its relation to the Sundaland of Dr. Molengraaff, a stable, but low-lying block, which is considered to have been dry land during the Glacial Period and again submerged on the melting of the Pleistocene ice-caps. There is also

considerable evidence that some of the lower parts of the Peninsula, e.g. the Perak valley and its tributaries, have been under the sea at no very distant date.

Throughout this book it is pleasant to note the indications of close co-operation for mutual benefit between the Malayan geologists and the highly efficient Netherlands Geological Survey in Java and Sumatra. A liaison has also been established with the French authorities further east, and it is only in Siam that our geological knowledge of south-east Asia shows a serious gap. No doubt the work of certain tin-mining companies in this direction will help to fill up this gap, in default of an organized survey in that country.

It would be possible to go on to an almost indefinite extent in enumerating points of interest raised by this book, but space forbids. It is all very well to go to the country now, to drive around in a comfortable car on splendid roads and report on its geology, but it wasn't like that when Mr. Scrivenor went there. He and his staff have had a hard time, and they still have in the remoter parts. It is perhaps permissible also to say a word of appreciation of the work done by those modestly described in the official reports as " Malay Collectors ". These men are often sent out without European leadership on difficult and dangerous journeys into the wilder parts of the country, and they bring back information of great value, showing remarkable discrimination in the notes and material collected.

In conclusion, it will doubtless be generally conceded that Mr. Scrivenor may regard the present work, his *Geology of Malayan Ore-Deposits* and his confessedly frivolous, but exceedingly entertaining and instructive production *A Sketch of Malayan Mining*, together with his official reports, as a monument of a life well-spent in the cause of science.

R. H. R.

OUTLINES OF HISTORICAL GEOLOGY. BY CHARLES SCHUCHERT. 2nd edition. pp. iv + 348, with 31 plates and 157 text-figures. New York: Wiley; London: Chapman and Hall, 1931. 15*s*.

IN its first incarnation, as explained in the preface, this book constituted the second and shorter half of Pirsson and Schuchert's *Introductory Geology*. It has now been considerably expanded and published separately, thus forming a very useful book. The treatment follows the usual lines, beginning with cosmogony: essentially the Jeans version of the near approach theory. The author has no use for cold planetismals,

but supports a molten globe. In this discussion there is a notable sentence, italicized by the author, thus : " The original crust of the earth was in consequence [of gravity differentiation] one of granite ". Using italics in our turn, we venture to ask " *Where is that crust now* " (or most of it) ?

The section devoted to the Pre-Cambrian rocks of the United States and Canada is extraordinarily good and clear, and may be read with profit by anyone who wants to get a vivid picture of the Canadian shield ; but British stratigraphers will doubtless be horrified to see nearly a page devoted to the mineral wealth of the Keweenawan ! The present reviewer must confess to a little surprise at finding *Eozoon* regarded as a fossil, probably a calcareous alga. Why should a calcareous alga show bands of serpentine ?

The treatment of the Lower Palaezoic is of course mainly based on the North American geosynclinals and diastrophic cycles : no one ever seems to make it clear in elementary books that these cycles are not world-wide but local, and that in other continents the succession of major events may be, and often is, entirely different. That American and Europe show a considerable resemblance in this respect is of course not just chance, and is in fact one of the most potent arguments in favour of continental drift.

In view of recent discussions in this country, in which his name has been prominently quoted, we naturally turn to Professor Schuchert's treatment of the Permian system. It is somewhat disappointing to find him still assigning the Gondwanaland glacials to the " late Middle Permian ". To put it mildly, there is now a considerable amount of evidence favouring a Carboniferous age for this episode. It really looks as if the Permian system is fated to be as much of a nuisance as the Silurian was in the last century.

It is a notable characteristic of even the most recent work that geologists in N.W. Europe and N. America are unable to shake themselves free from the obsession of the Carboniferous, as originally defined from the peculiar facies of those areas. Even the modern American tendency to split the Carboniferous into Mississippian and Pennsylvanian is in reality only an accentuation of this obsession. The sequence of Mountain Limestone followed by Coal Measures is purely local. There are places where the lithological succession is Coal Measures, followed by Mountain Limestone : or it may be limestone all through. In S. Africa again we have Millstone Grits from the Devonian upwards, followed by Coal Measures which end in the Rhaetic. The Table Mountain Sandstone is very like the Millstone Grit, and even the fossiliferous Bokkeveld beds are partly sandstones, e.g. at De Doorns in the Hex River Pass, whence many of the best specimens have come. The fact is that the southern facies

does not fit in anyhow with the North Atlantic facies: the divisions founded on diastrophism come in different places in the time-scale and consequently the lithological types may be in the wrong order. In Africa it is impossible to say what represents the Carboniferous Limestone of Europe or of the northern part of the Malayan area, and unfortunately the time-relations of the two last-named are still very obscure, as shown in Mr. Scrivenor's new book reviewed on another page of this number. While on this subject it may be mentioned that a very comprehensive correlation of South African rocks up to Northern Rhodesia, Katanga, Tanganyika, and Somaliland, so far as now known, appeared in the *Mining Magazine* for April of the present year.

Professor Schuchert's treatment of stratigraphy is of course largely palaeontological, but much attention is paid to geography, and there are many palaeo-maps. As in all American books, too much space is devoted to figures of theatrical reconstructions of wildly improbable animals: the picture on p. 217 of the thin and earnest young dinosaur taking his morning run on the beach is very charming, while on p. 290 the most primitive cat chasing an early and very knobby ruminant is worthy of the *Just-so Stories*. Many of the photographs of scenery are remarkably effective, especially as they are not printed on special plate paper, which adds so much to the weight and cost of many books.

This book will be of great value to students who wish to obtain a general idea of how stratigraphical geology presents itself to one of the foremost authorities on the other side of the Atlantic. It is eminently readable and broad in its outlook, without too much insistence on local detail in any area, which is just what is wanted by European geologists who are not specialists in any one department.

[Since this review was written, the Editor is informed by the publishers that this work, together with Professor Chester R. Longwell's *Outlines of Physical Geology*, are now to be obtained combined in one volume at the price of 25*s*.]

DETERMINATION OF THE OPAQUE MINERALS. By C. M. FARNHAM. pp. vii + 236. London: McGraw Hill Publishing Co., Ltd., 1931. Price 17*s*. 6*d*. net.

FOUR years after the appearance of Murdoch's pioneer tables, W. M. Davy and C. M. Farnham published in 1920 a new version of determinative tables for the opaque minerals, based on etch-reactions in place of the fine colour-distinctions used by

Murdoch. The volume under review is a considerably expanded edition by one author. The first 128 pages contain descriptions of over 200 opaque minerals and associated species, including where possible a brief account of their optical properties under vertical illumination. The determinative tables which follow are still based on etch-reactions; and further tables deal with colour, hardness, special chemical tests, etc.

The need of an up-to-date summary of this kind in English must be apparent to all mineragraphic workers, but the true value of the present work is somewhat difficult to assess. It would be unfair to criticize the continued exclusive use of etch-reactions for determination, since the book is avowedly written for "economic geologists and mining engineers", to whom no complicated apparatus is available. No appeal to a special public, however, can excuse the careless nature of the bibliographical details. Mis-spelling of authors' names (Murdock, Bouchert, P. Geiger), their confusion (Ellis Thomson and A. P. Thompson), or even their invention (Berezof) may be merely annoying, but wrong references to page and volume, the omission of such details as Beilage Band, the constant references to *Mining Magazine* where *Mineralogical Magazine* is intended, and a translation by which Zinnkies becomes Zinkenite (!) are errors of increasing gravity. The prevalence of "slips" of this kind produces a feeling of uncertainty as to the reliability of the more fundamental information here assembled, a reliability which can only be tested in practical use.

F. C. P.

Outlines of Palaeontology. By H. H. Swinnerton. Second edition. pp. xii + 420. London: E. Arnold, 1930. Price 21*s*.

THIS edition differs but little from the earlier one, but the reduction in price will place it within the reach of a larger number of students.

A General Index to the Journal of Geology, Vols. I–XXXV, 1893 to 1927. Edited by R. T. Chamberlin. pp. 279. The University of Chicago Press, Chicago, and The Cambridge University Press. 1930. Price 32*s*. 6*d*.

THERE is no doubt that publications of this kind are of very great value and save an enormous amount of time in looking up references, especially when such are incorrect. The amount of labour involved in such a compilation is necessarily very large, but it is undoubtedly well-expended. We have found a few printers' errors and here and there a somewhat erratic use of capital letters, e.g. p. 82, "Flett and Hill, Geology of the lizard and meneage," but these are minor blemishes.

BIBLIOGRAPHIA PALAEONTOLOGICA für die Jahre 1914–26. Von E. JAWORSKI. Lief. 1. pp. x + 223. Leipzig: Max Weg. 1931. Price 18 marks.

THE special value of this bibliography is due to the classification, which renders it easy to find out what has been published on any branch of palaeontology. For example, general subjects are divided into 1, Bibliographies; 2, Fossilization; 3, Systematics and Nomenclature; 4, Correlation and Chronology; 5, Palaeobiology; 6, Palaeozoogeography and Palaeophytogeography; 7, Palaeoclimatology; 8, Phylogeny, etc. The Phyla are divided into smaller groups, which are usually subdivided stratigraphically, and sometimes geographically. If this work is continued it will be of great value to palaeontologists and stratigraphical geologists.

PLANT LIFE THROUGH THE AGES. By A. C. SEWARD. pp. xxi + 601, 139 figures. Cambridge University Press. 1931. Price 30*s*.

THIS book on fossil floras is primarily intended for the "general reader" who is assumed to know no technical geology and no botany—beyond the names of familiar plants. For my part, if I knew neither botany nor geology I doubt if I would have the courage to face such a considerable book on the borderline subject; but it is certainly very well suited to those already familiar with the outlines of botany and geology, and it will be a great help also to more specialized readers—including palaeobotanists.

It is complementary to the existing text-books of palaeobotany: it is arranged on a geological basis and as much of the text is devoted to geology as to botany. Details of plant structure and of evolutionary theory are omitted, but there are innumerable references in the text and there are tables at the end of the discussion of each period, giving references to all the chief floras.

A noteworthy feature is the emphasis laid on rocks and specimens rather than on the deductions based on them. It is an exposition of the views now held, by no means a speculative work.

The first quarter of the book deals with subjects like classification of plants, continental drift, etc., and the general reader is introduced to stratigraphy and mountain-building. The next chapters are on the oldest records of plant life—*Cryptozoon*, etc., of the Pre-Cambrian, which Professor Seward regards as inorganic, and also on the genuine algae of the older Palaeozoic. In the chapter on the Devonian we come to the first and most interesting fossil land flora, the elucidation of which has been the great achievement of palaeobotany in the last fifteen years. The scrubby plants of this period still seem hardly real, though by now restorations of *Lepidodendron* are nearly as familiar as living trees. Professor Seward favours the view that the first land plants are descended from highly

organized seaweeds which were raised by an uplift of the sea bottom and so came to living on land ; but the adaptation of the structure of the Devonian plants to land life shows them to have been terrestrial for a very long time.

In the chapters on the Carboniferous and Permian, there is a summary of Davies' statistical work on Coal Measure floras and also an interesting comparison of the different floral regions then existing. Few startling discoveries have been made in recent times on the floras of the Mesozoic and Tertiary and our conception of the vegetation of those times is probably rather similar to what it was twenty or thirty years ago, except that we are now doubtful about certain things then taken for granted. The main problem—the rise of the flowering plants—is as mysterious as ever.

In the discussion of past climates which occupies a considerable part of the later chapters Professor Seward is cautious—he points out that the occurrence of a tropical type of flora in the far north can as well be taken to indicate a change in plants as in climates. It is only the living species of the Quaternary on which he relies for indications of climate.

The book contains a great number of maps and of very good illustrations of rocks, living plants and fossils, but its main feature is a series of excellent restorations of past landscapes. Some of these—notably the Oligocene landscape—are inviting enough to be used as railway posters.

T. M. Harris.

Spectrum Analysis in Mineralogy. By A. A. Fitch, A.R.C.S., D.I.C., Ph.D., F.G.S. pp. 52, 6 plates, 3 drawings. Published by Adam Hilger, Ltd.

THIS is a very useful and simple account of the use that can be made of spectrum analysis in determinations both of the quantity and the character of elements present in minerals. The technique is clearly and concisely described and the several plates and line drawings are aptly chosen. The full bibliography should prove very helpful to anyone taking up this type of work.

W. A. Wooster.